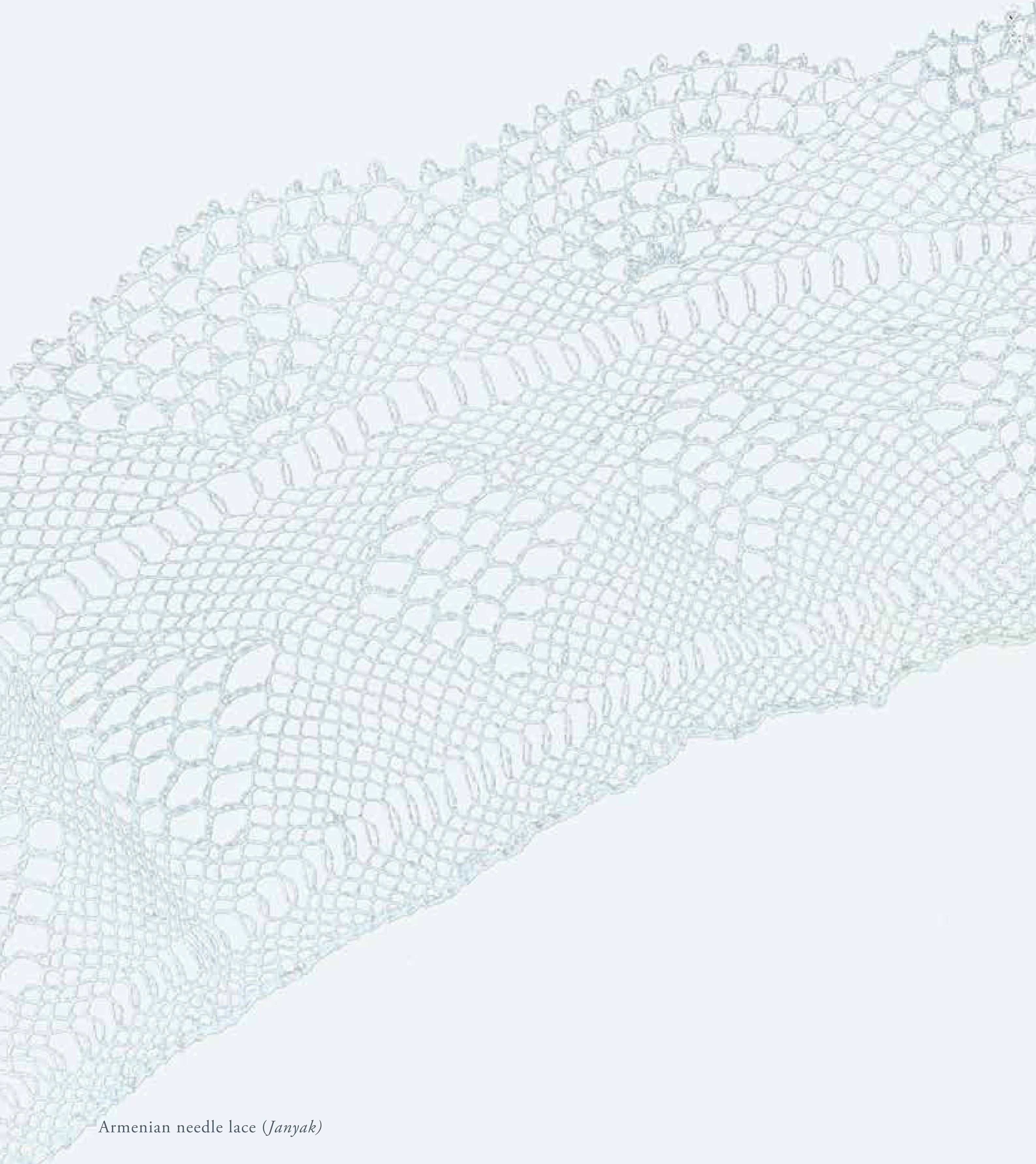
Agency for Cultural Affairs Commissioned Project 2022
International Cooperation in Cultural Heritage Institutional Exchange Project
"International Exchange Project in Human Resource Development for
the Preservation of Cultural Heritage in the Republic of Armenia."

Conservation of Textiles in Museums

MIE ISHII

ARMENIA



Armenian needle lace (*Janyak*)

Acknowledgments

First of all, I would like to express my heartfelt gratitude to the people of Armenia, especially to the Armenian Orthodox Church, Catholicos Garegin II, for the exchanges with Japan.

I dedicate this book to my irreplaceable friends in Armenia. This textbook was born out of 10 years of exchanges through the conservation and restoration of textiles between Armenian textile conservators Ms. Maro Harturyan (National History Museum of Armenia) and Ms. Marine Petrosyan (Holy Mother See of Etchmiadzin Museums). As part of the 2022 Cultural Heritage International Cooperation Base Exchange Project commissioned by the Agency for Cultural Affairs, "International Exchange Project in Human Resources Development for the Preservation of Cultural Heritage in the Republic of Armenia," the workshop materials were put together into textbooks in Armenian, Japanese, and English. I hope these may help many other people who share the same desire to preserve the historic textiles in their care.

I would like to express my deepest gratitude to everyone who has supported and cooperated with our activities between Armenia and Japan. We have made good friends and I wish for peace for our world.

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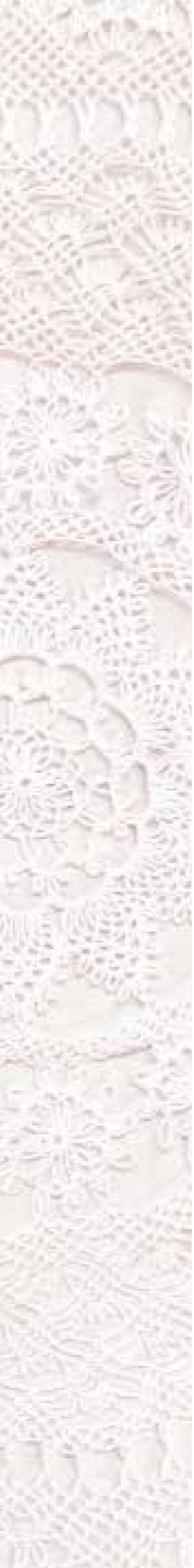

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1 Introduction

> What we conserve is a statement of what we respect, who we are and who we wish to be. Conservation therefore not only sustains and refreshes values of the past – giving us an understanding of where we have come from – but also reflects values for the present and the future[1].

Textiles contain a wealth of information about our culture and history. A textile that is a 'consumer asset' decorates our body and home for protection and pleasure. Its cleanliness and maintenance are aimed for a limited time until they are discarded. A textile of 'cultural asset' or 'cultural heritage' is a textile in which historic value is found. Prolonging its existence will testify to some aspects of human activity in the past. Therefore, it is natural that the care and maintenance of textiles of historic value differ from that of commodity textiles.

Textile conservation aims to preserve such cultural significance and to foster understanding and use of textiles and dress in collections. The attitudes fundamental in conducting conservation work are the recognition and respect for individual artefacts' cultural and physical integrity and authenticity. To practice textile conservation a wide range of knowledge and skills are required including aesthetic appreciation of the textile's appearance, connoisseurship of textile fabrication, understanding of the physical and chemical properties of the materials and their degradation, information about the history, culture, sociology, ethnography, anthropology, and archaeology, knowledge of conservation history and the concepts of conservation ethics, manual dexterity to conduct delicate conservation-restoration treatments, and management skills for storage maintenance, display, and transportation.

Such principles, instrumentation, and practice are "tools" to help the textile conservator carry out the important work of preserving our textile heritage[2].

1. The role of UNESCO in heritage preservation: post-1945

http://www.unesco.org

World War II (1939-45) resulted in devastating consequences for humanity and cultural and natural heritage. Founded in 1945, United Nations Educational, Scientific and Cultural Organization (UNESCO) promotes peace and social development through heritage preservation. Several sub-organizations within UNESCO assist its mission. The following is its principle and affiliated institutions.

Constitution of UNESCO
November 16, 1945

The Governments of the States Parties to this Constitution on behalf of their peoples declare:
That since wars begin in the minds of men, it is in the minds of men that the defences of peace must be constructed;

That ignorance of each other's ways and lives has been a common cause, throughout the history of mankind, of that suspicion and mistrust between the peoples of the world through which their differences have all too often broken into war;

That the great and terrible war which has now ended was a war made possible by the denial of the democratic principles of the dignity, equality, and mutual respect of men, and by the propagation, in their place, through ignorance and prejudice, of the doctrine of the inequality of men and races;
That the wide diffusion of culture and the education of humanity for justice and liberty and peace are indispensable to the dignity of man and constitute a sacred duty which all the nations must fulfil in a spirit of mutual assistance and concern;

That a peace based exclusively upon the political and economic arrangements of governments would not be a peace which could secure the unanimous, lasting, and sincere support of the peoples of the world, and that the peace must therefore be founded, if it is not to fail, upon the intellectual and moral solidarity of mankind.

For these reasons, the States Parties to this Constitution, believing in full and equal opportunities for education for all, in the unrestricted pursuit of objective truth, and in the free exchange of ideas and knowledge, are agreed and determined to develop and increase the means of communication between their peoples and to employ these means for the purposes of mutual understanding and a truer and more perfect knowledge of each other's lives.

In consequence whereof, they do hereby create the United Nations Educational, Scientific and Cultural Organization for the purpose of advancing, through the educational and scientific, and cultural relations of the peoples of the world, the objectives of international peace and of the common welfare of mankind for which the United Nations Organization was established and which its Charter proclaims.

https://www.unesco.org/en/legal-affairs/constitution

UNESCO conventions, recommendations, declarations related to culture and heritage preservation

https://www.unesco.org/en/legal-affairs/standard-setting/conventions

2015 Recommendation of concerning the protection and promotion of museums and collections, their diversity and their role in society
2015 Recommendation concerning the preservation of, and access to documentary heritage including in digital form
2011 Recommendation on Historic Urban Landscape, including a glossary of definitions
2005 Convention on the Protection and Promotion of the Diversity of Cultural Expression
2003 Declaration Concerning of the Destruction of Cultural Heritage
2003 Convention for the Safeguarding of Intangible Cultural Heritage
2003 Charter on the Preservation of Digital Heritage
2001 Convention on the Protection of Underwater Cultural Heritage
2001 Universal Declaration on Cultural Diversity
1989 Recommendation on the Safeguarding of Traditional Culture and Folklore
1980 Recommendation Concerning the International Standardization of Statistics on the Public Financing of Cultural Activities
1980 Recommendation for the Safeguarding and Preservation of Moving Images
1978 Recommendation for the Protection of Moveable Cultural Property
1976 Recommendation Concerning the International Exchange of Cultural Property
1976 Recommendation on Participation by the People at Large in Cultural Life and Their Contribution to It
1976 Recommendation Concerning the Safeguarding of the Contemporary Role of Historic Areas
1972 Convention Concerning the Protection of the World Cultural and Natural Heritage
1972 Recommendation Concerning the Protection, at a National Level, of Cultural and Natural Heritage
1970 Convention on the Means of Prohibiting and Preventing the Illicit Import, Export and Transfer of Ownership of Cultural Property
1968 Recommendation Concerning the Preservation of Cultural Property Endangered by Public or Private Works
1966 Declaration of Principles of International Cultural Co-operation
1964 Recommendation on the Means of Prohibiting and Preventing the Illicit Export, Import and Transfer of Ownership of Cultural Property
1962 Recommendation for Safeguarding the Beauty and Character of Landscape and Sites
1960 Recommendation Concerning the Most Effective Means of Rendering Museums Accessible to Everyone
1956 Recommendation on International Principles Applicable to Archaeological Excavations
1954 Convention for the Protection of Cultural Property in the Event of Armed Conflict with Regulations for the Execution of the Convention (The Hague Convention)

1.1 ICOMOS International Council of Monuments and Sites (est. 1964)

https://www.icomos.org/

The history of heritage conservation has been led by a regional campaign on monument protection. In 19th century Britain, the industrial revolution exploited the county side and demolished ancient buildings. In 1877, William Morris (1834-96) and other supporters, influenced by John Ruskin's (1819-1900) ideas on ancient monument protection, set up The Society for the Protection of Ancient Buildings (http://www. spab.org.uk/) in London, which still exists today. They protested the scraping of ancient materials in "restoration" and "repair," that lead to the loss of material, technique, romance, and authenticity. The first international manifesto on monuments protection was the Athens Charter for the Restoration of Historic Monuments, adopted at the First International Congress of Architects and Technicians of Historic Monuments in 1931. The 1964 Venice Charter was issued after the flood in Venice (1963). ICOMOS succeeds such concerns in history and coordinates international effort to protect and conserve cultural heritage places.

ICOMOS charters, recommendations, and declarations

https://www.icomos.org/en/resources/charters-and-texts

2021 ICOMOS Guideline for Fortifications and Military Heritage
2017 Principles for the Conservation of Wooden Built Heritage
2017 Salalah Guidelines for the Management of Public Archaeological Sites
2011 The Valletta Principles for Safeguarding and Management of Historic Cities, Towns and Urban Areas
2008 Quebec Declaration on the Preservation of the Spirit of the Place
2008 Charter on the Interpretation and Presentation of Cultural Heritage Sites
2008 Charter on Cultural Routes
2005 Xi'an Declaration on the Conservation of the Setting of Heritage Structures, Sites and Areas
2003 Principles for the Preservation and Conservation-restoration of Wall paintings
2003 Charter – Principle for the Analysis, Conservation and Structural Restoration of Architectural Heritage
1999 Charter on the Built Vernacular Heritage
1999 Principles for the Preservation of Historic Timber Structures
1999 International Cultural Tourism Charter
1999 Charter on the Protection and Management of Underwater Cultural Heritage
1998 Stockholm Declaration: Declaration of ICOMOS Marking the 50th anniversary of the Universal Declaration of Human Rights
1996 Principles for the Recording of Monuments, Groups of Buildings and Sites
1996 Declaration of San Antonio
1996 Charter for the Protection and Management of Underwater Cultural Heritage
1994 Nara Document on Authenticity (Nara, Japan)
1990 Charter for the Protection and Management of Archaeological Heritage
1987 Charter for the Conservation of Historic Towns and Urban Areas (Washington Charter)
1983 Declaration of Rome
1982 Declaration of Dresden
1982 The Florence Charter (Historic Gardens and Landscapes)
1982 Tlaxcala Declaration on the Revitalization of Small Settlements
1981 The Australia ICOMOS Charter for the Conservation of Places of Cultural Significance (The Burra Charter)
1976 Charter of Cultural Tourism
1975 Resolution on the Conservation of Smaller Historic Towns
1972 Resolutions of the Symposium on the Introduction of Contemporary Architecture into Ancient Groups of Buildings
1964 International Charter for the Conservation and Restoration of Monuments and Cities (Venice Charter, Italy)

1.2 ICOM International Council of Museums (est. 1946)

https://www.icom.museum/en/

ICOM works for society and its development through the protection and conservation of cultural property. It plays a significant role in promoting professional practices in museums worldwide. The Code of Ethics for Standard Practice (1986, 2004) [3], translated into 36 languages, provides the basic principles of collection care for museum professionals.

A specialized working group focused on conservation is the ICOM-Conservation Committee (ICOM-CC est. 1966) which organizes biannual meetings. The Textile Working Group discusses issues around textile conservation[4].

The ICOM-Costume Committee (est. 1962, http://www.costume-committee.org) is another group that is committed to the study, interpretation, and preservation of all aspects of clothing. They organize annual meetings and issue documents such as Guideline for Costume (1986, updated 1998), and Vocabulary of Basic Terms for Cataloguing Costume (1982).

In 2022 ICOM adopted a new museum definition. "A museum is a not-for-profit, permanent institution in the service of society that researches, collects, conserves, interprets and exhibits tangible and intangible heritage. Open to the public, accessible and inclusive, museums foster diversity and sustainability. They operate and communicate ethically, professionally and with the participation of communities, offering varied experiences for education, enjoyment, reflection and knowledge sharing."

2. IIC International Institute for Conservation of Historic and Artistic Works (est. 1950)

https://www.iiconservation.org/

IIC is an independent institute for academic studies in conservation. The bulletin, Studies in Conservation succeeds the bulletin of the same title with a subtitle, Technical Studies in the Field of Fine Art, issued by the Harvard Museum, Fogg Institute, published 1930-1942. IIC follows the principle that the conservation of artefacts is based on the scientific study of the techniques used. They organize an international conference every two years with a focus on a current topic.

IIC International Institute for Conservation, Biannual Congress

https://www.iiconservation.org/publications/congress

2022 Conservation and Change: Response, Adaptation and Leadership. (Wellington)
2020 Practices and Challenges in Built Heritage Conservation (Edinburgh)
2018 Preventive Conservation: The State of the Art (Turin)
2016 Conserving the Now: Crossing Boundaries to Conserve Contemporary Works (Los Angeles)
2014 Unbroken History: Conserving East Asian Art and Heritage (Hong Kong)
2012 The Decorative: Conservation and Applied Arts (Vienna)
2010 Conservation and the East Mediterranean (Istanbul) 2008 Conservation and Access (London)
2006 The Object in Context: Crossing Conservation Boundaries (Munich).
2004 Modern Art: New Museums (Bilbao)
2002 Works of Art on Paper, Books, Documents and Photograph: Techniques and Conservation (Baltimore)
2000 Tradition and Innovation: Advances in Conservation (Melbourne)
1998 Painting Techniques: History, Materials and Studio Practice (Dublin)
1996 Archaeological Conservation and its Consequences (Copenhagen)
1994 Preventive Conservation (Ottawa)
1992 Iberian and Latin American Cultural Heritage (Madrid)
1990 Cleaning, Retouching and Coatings (Brussels) 1998 Far Eastern Art (Kyoto)
1996 Paintings (Bologna)
1984 Adhesives and Consolidants (Paris) 1982 Science and Technology (Washington)
1980 Conservation Within Historic Buildings (Vienna) 1978 Wood in Painting and the Decorative Arts (Oxford)
1975 Archaeology and the Applied Arts (Stockholm) 1972 Paintings and the Graphic Arts(Lisbon)
1970 Stone and Wooden Objects (New York) 1967 Museum Climatology (London)
1964 Textile Conservation (Delft)
1961 Recent Advances in Conservation (Rome)
1950 IIC established in London

3. Japan's international role in heritage conservation

Located in a tropical climate with frequent natural disasters, historic timber buildings in Japan have been preserved by continuous repair utilizing traditional skills. Westernization from the late 19th century has threatened traditional lifestyle, performing arts and craft skills. The 1951 Law on the Preservation of Cultural Property legislated the protection of both tangible and intangible cultural heritage. Monuments, artefacts and living artisans are appointed as national treasures or important cultural property. This national living treasure system is unique within the world. Since the mid-1990s, Japan has been actively addressing issues of heritage conservation in areas overlooked by Western values. The 1994 ICOMOS Nara Charter for Authenticity acknowledged that traditional skills necessary to preserve historic buildings are also a valuable part of the tangible heritage. This led to the 2003 UNESCO Convention on the Protection of Intangible Cultural Heritage, and the 2004 UNESCO Yamato Declaration on Integrated Approach for Safeguarding Tangible and Intangible Cultural Heritage.

Japan also initiated the UNESCO 2003 Declaration Concerning the Destruction of Cultural Heritage, addressing concerns about the destruction of the Giant Buddha at Bamiyan, Afghanistan. In 2007 the Japanese government established the Law on the Promotion for International Protection of Cultural Heritage Abroad. The National Research Institute for Cultural Properties, Tokyo, is working towards the preservation of the remains of the Giant Buddha in Bamiyan. They also initiate educational programs in heritage conservation around the Asia region. Japan Foundation promotes international cultural exchange and organizes and supports educational programs in heritage conservation. Since 2011, the following three organisations have supported exchange programs between Japan and Armenia for museum and conservation specialists. Preservation of cultural heritage is a global issue and we hope that our endeavours will help towards a sustainable and peaceful future.

Japan Foundation
https://www.jpf.go.jp/e/about/index.html

Tokyo National Research Institute for Cultural Properties
https://www.tobunken.go.jp/index_e.html

Agency for Cultural Affairs Cultural Heritage Protection International Contribution Program
https://www.bunka.go.jp/seisaku/kokusaibunka/bunkazaihogo/kokusai_koken/index.html

4. Pioneering practice in textile conservation

The first museum-based textile conservation studio was established in Sweden in 1908 (former Pietas Association, now Museum of National Antiquities, Stockholm)[5]. Agnés Geijer (1898- 1989), who had obtained a PhD in archaeological textiles in Sweden, became the head of Pietas in 1930.

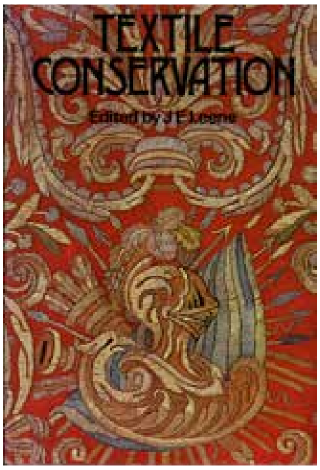

Fig. 1.2 Textile Conservation 1972

The Centre International d'Etude des Textile Ancien (CIETA est. 1954) was the first international gathering where issues on historic textiles and textile conservation were discussed. At a meeting in 1960 (Lyon), Jentina Leene (Delft University of Technology, The Netherlands) presented a case study on a treatment of a silk flag using synthetic adhesives. This stirred an active debate among conservators who traditionally used stitching and natural adhesives for textile conservation-restoration. Geijer[6] expressed concern about the new chemical method in the CIETA bulletin titled "Dangerous methods for conservation of textiles", and stated that knowledge of textile history, materials, understanding the long-term effect of a treatment, and ethics for professional practice were essential to conducting the important practice of textile conservation. In return, Leene[7] explained her approach from a scientific point in the next CIETA Bulletin, "Response to Dr Angés Geijer." This open discussion between Leene and Geijer was furthered at the first international conference on conservation held by the International Institute for Conservation (IIC est. 1950) entitled Recent Advances in Conservation (Rome, 1961)[8-9.] This led to the second IIC conference titled Textile Conservation (Delft, 1964)[10] which became a milestone in the history of textile conservation. Conservation ethics, conservation-restoration techniques, and conservation science were all recognized as necessary disciplines to preserve historic textiles. The conference papers lead to the publication of Textile Conservation (1972)[11] the first academic reference on the subject.

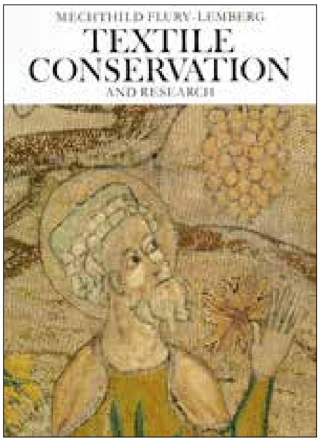

Fig. 1.3 Textile Conservation and Research 1989

Pioneering textile conservators who actively presented issues on textile conservation and trained many younger generations are, in Europe, Mechtild Flury- Lemberg[12] (Abegg-Stiftung, Switzerland), Sheila Landi[13] (Victoria and Albert Museum U.K.), Karen Finch[14] and Dinah Eastop (Textile Conservation Centre, U.K.), and in North America, Margaret Fikioris (Henry Francis du Pont Museum, University of Delaware, U.S.A.), Joseph Columbus (Textile Museum, U.S.A.) and Nobuko Kajitani[15] (Metropolitan Museum of Art, U.S.A.). Conservation scientists who have endeavoured to explain the chemical principles of textile conservation are James Rice[16] (Textile Museum, U.S.A.), Judith H. Hofenk de Graaff (Netherlands Institute for Cultural Heritage), Lilian Masschelein-Kleiner[17] (The Royal Institute for Belgium's Artistic Heritage) and Ágnes Tímár-Balázsy[18] (Hungarian National Museum).

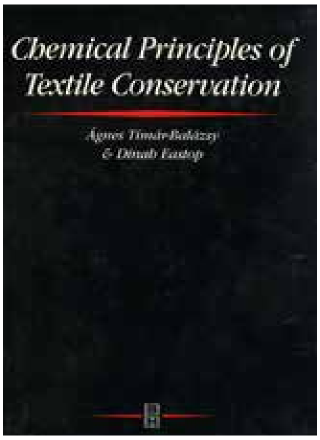

Fig. 1.4 Chemical Principles of Textile Conservation1998

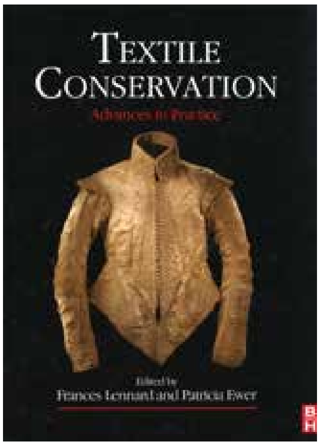

Fig. 1.5 extile Conservation Advances in Practice 2009

5. Textile conservation in Japan

There is a long history of textile preservation in Japan. Shosoin, the treasure house of Todaiji Temple (now under the Imperial Household Agency), Nara, has preserved treasures from the 8th century in Azekura-style timber architecture. Cataloguing and repair of textile treasures began in 1914 and is still conducted today. Textiles were often pasted onto paper using techniques derived from paper conservation. In recent years, a more minimal approach is being employed, influenced by the values of authenticity and modern conservation practice[19]. Japanese conservation publications are now being published in English for a wider audience, many of which can be accessed online (see Fig. 1.9-13 and references 30-34).

Fig. 1.6 Changing Views of Textile Conservation 2011

6. Primary publications on textiles and textile conservation

Treatment methodology for textile conservation is explained in Ágnes Tímár-Balázsy and Dinah Eastop's (Textile Conservation Centre U.K.) Chemical Principles of Textile Conservation (1998)[20]. Diversity within the field of textile conservation is demonstrated in Textile Conservation: Advances in Practice (2009)[21]. The evolution of textile conservation in the post-war era is reflected in collected papers published in Changing Views of Textile Conservation (2011)[22]. The Primary Structure of Fabrics: An Illustrated Classification (1966)[23] is the primary reference of fabric analysis. Textile techniques are explained in Textiles: A Classification of Techniques (1995)[24]. Natural Dyes: Sources, Tradition, Technology and Science (2007)[25] and The Colourful Past: Origins, Chemistry and Identification of Natural Dyes (2004)[26] deal with historic dyes and their identification. References for fibre identification are Microscopy of Textile Fibres (1995)[27] and Identification of Textile Fibres (2009)[28].

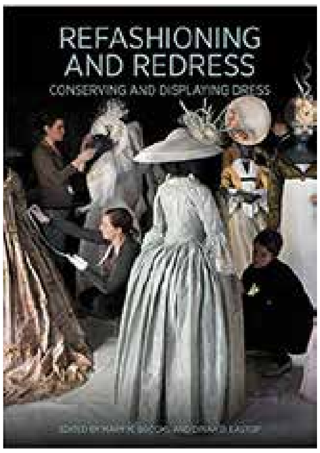

Fig. 1.7 Refashion and Redress 2016

7. Databases containing information on studies in conservation

Getty Conservation Institute (Los Angeles, U.S.A) AATA Online (abstract search)
https://aata.getty.edu/primo-explore/search?vid=AATA

BCIN (The Bibliographic Data Base of the Conservation Information Network) Canadian Conservation Institute (Canada, Ottawa)
Conservation Information Network (abstract search in English and French)
https://www.bcin.ca/English/home_english.html

JSTOR
https://www.jstor.org/

Science Direct
https://www.sciencedirect.com/

Google Scholar
https://www.scholar.google.com/

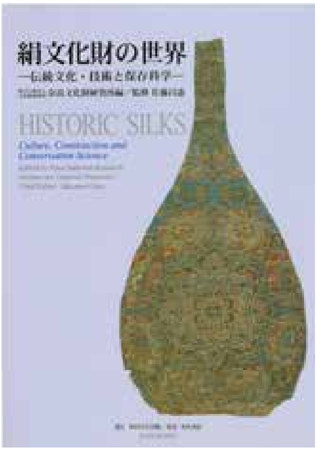

Fig. 1.8 Historic Silks 2005

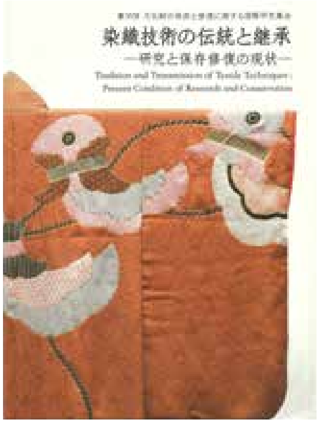

Fig. 1.9 Transmitting Traditions of Textile Technique 2012

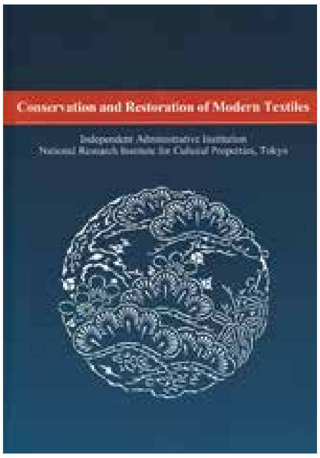

Fig.1.10 Conservation and Restoration of Modern Textiles 2015

8. Textile conservation education

University of Glasgow, Glasgow, U.K.
The Centre for Textile Conservation and Technical Art History (Textile Conservation Centre Foundation, est. 1975)
2-year M.Phil. in Textile conservation
https://www.gla.ac.uk/postgraduate/taught/textileconservation

Abegg-Stiftung, Bern, Switzerland (est. 1961)
3-year B.A. + 2-year M.A. Textile conservation in affiliation with Bern Institute of Technology.
https://abegg-stiftung.ch/en/training/

Institut National du Patrimoine, Paris, France (est. 1990)
5-year Diploma in cultural heritage restoration (textile speciality available)
https://www.inp.fr/en/Initial-and-continuing-education/Department-of-conservators

Cologne University of Applied Sciences, Cologne, Germany, Cologne Institute for Conservation Sciences
B.A., M.A. in Textiles and Archaeological Fibres
https://www.th-koeln.de/en/academics/restoration-and-conservation-of-art-and-cultural-property-bachelors-program_7339.php

University of Delaware, Winterthur, U.S.A. (est. 1974) 4-year B.A. in Art Conservation
3-year M.A. in Art Conservation (textile speciality available)
https://www.artcons.udel.edu/

Faculty of Art and Regional Design, Saga University, Graduate School of Regional Design (Textile Conservation and Restoration Science)
http://www.art.saga-u.ac.jp/postgraduate/
Queen's University, Kingston, Canada
2-year M.A.C. in Art Conservation (textile speciality available)
https://www.art.saga-u.ac.jp/english/graduate/

A list of art conservation training courses around the world
https://en.wikipedia.org/wiki/Category:Conservation_and_restoration_training

9. Other events related to textile conservation

The North American Textile Conservation Conference (NATCC)
https://www.natcconference.com/publications

2021 Outside Influences (Virtual)
2019 Lessons Learned: Textile Conservation- Then and Now (Ottawa-Gatineau)
2017 Embellished Fabrics: Conserving Surface Manipulation and Decoration (Mexico City)
2015 Material in Motion (New York, U.S.A.)
2013 Conserving Modernity: The Articulation of Innovation (San Francisco, U.S.A.)
2011 Playing the Trades: Pulling Together in the 21st Century (Oaxaca, Mexico)

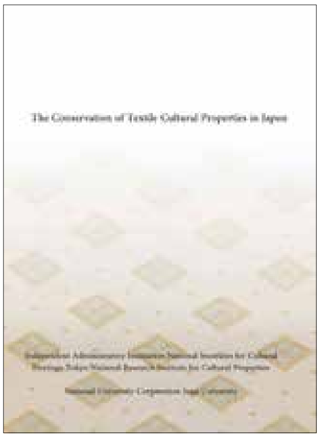

Fig. 1.11 Conservation of Textile Cultural Properties in Japan 2018

2009 Conservation of Three-Dimensional Textiles (Quebec City, Canada)

2007 Facing Impermanence: Exploring Preventive Conservation for Textiles (Washington D.C. U.S.A.)

2005 Recovering the Past: The Conservation of Archaeological and Ethnographic Textiles (Mexico City, Mexico)

2003 The Conservation of Flags and Other Symbolic Textiles (Albany, U.S.A.)

2002 Strengthening the Bond: Science and Textiles (Philadelphia, Winterthur U.S.A.)

2000 Conservation Combinations (Ashville, U.S.A.)

1997 The Fabric of an Exhibition (Ottawa, Canada)

10. Chronological events related to cultural heritage preservation

2016 Saga University, Faculty of Art and Regional Design established (Japan)

2010 University of Glasgow, MPhil Textile Conservation started. (U.K.) (The Textile Conservation Centre (TCC) Foundation was established at the University of Glasgow)

2007 Law on the Promotion for International Protection of Cultural Heritage Abroad (Japan)

1999 The Textile Conservation Centre (TCC), University of Southampton, MA Textile Conservation started. (The Centre relocated from the Courtauld Institute of Art, University of London and closed in 2009. Moved to the University of Glasgow in 2010.)(U.K)

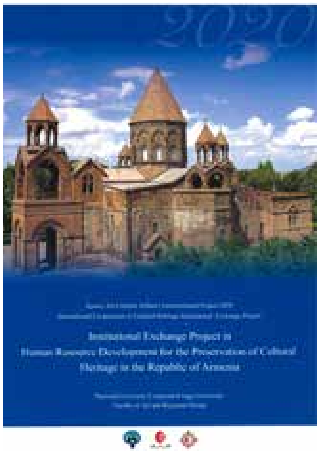

Fig. 1.12 Human Resource Development for the Preservation of Cultural Heritage in the Republic of Armenia 2021

1994 North American Textile Conservation Conference (every 2 years) started.

1990 Institut National du Patrimoine, Diploma in art conservation started, Paris. (France)

1981 Getty Conservation Institute was established. Los Angeles (U.S.A.)

1978 The Textile Conservation Centre, Courtauld Institute of Art, Postgraduate Diploma in Textile Conservation, started, London. (U.K.)

1975 The Textile Conservation Centre (TCC) was established. (U.K.)

1974 University of Delaware, BA/MA Art conservation course, started. (U.S.A.)

1961 Abbeg-Stiftung established. Bern. (Switzerland)

1954 Centre International d'Etude des Textile Anciens (CIETA) established. Lyon. (France)

1951 Law on Preservation of Cultural Heritage. (Japan)

1939-45 WWII

1931 Athens Charter (on the protection of ancient monuments) (Congré International d'Architecture Modern, CIAM.

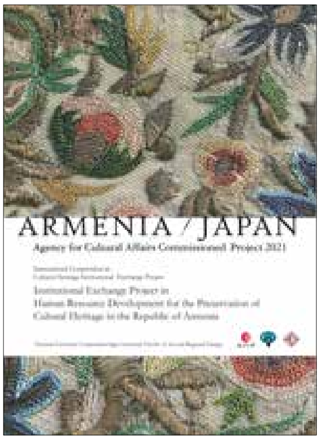

Fig. 1.13 Human Resource Development for the Preservation of Cultural Heritage in the Republic of Armenia 2022

1914 Shosoin (Todaiji treasure house, Imperial household agency), textile repair begins, Nara. (Japan)

1908 Pietas Association was established at the National Museum of Antiquities, Stockholm. (Sweden) (The first textile conservation studio in a national museum in Europe.)

1904 The Preservation and Restoration of Architectural Monuments, (The 6th International Congress of Architect Madrid)

1887 Historical Monuments Act, (France)

1882 Ancient Monuments Protection Act. (U.K.)

1877 Society for the Protection of Ancient Buildings (President: William Morris), London. (U.K.)

1873 National Monuments Preservation Bill. (U.K.)

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Appendix

Code of Ethics

&

Guidelines for Conservation

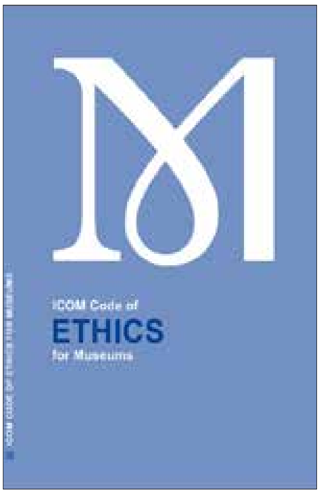


Fig. 1.1 ICOM Code of Ethics for Museums 2004

ICOM Code of Ethics for Museums (adopted 1986, revised 2004)

https://icom-museum/wp-content/uploads/2018/icom-code-En-web.pdf

The ICOM Code represents a minimum standard for museums. It is presented as a series of principles supported by guidelines for desirable professional practice. In some countries, certain minimum standards are defined by law or government regulation. In others, guidance on and assessment of minimum professional standards may be available in the form of 'Accreditation', 'Registration', or similar evaluative schemes. Where such standards are undefined, guidance can be sought through the ICOM Secretariat, a relevant National Committee of ICOM, or the appropriate International Committee of ICOM. It is intended that individual nations and the specialized subject organizations connected with museums should use this Code as a basis for developing additional standards. (The following is an excerpt from the Code.)

Section II Museums that Maintain Collections Hold Them in Trust for the Benefit of Society and its Development.

CARE OF COLLECTIONS

2.18 Collection Continuity

The museum should establish and apply policies to ensure that its collections (both permanent and temporary) and associated information, are properly recorded, available for current use, and will be passed on to future generations, in as good and safe a condition as practicable, according to current knowledge and resources.

2.19 Delegation of Collection Responsibility

Professional responsibilities involving the care of the collections should be assigned to persons with appropriate knowledge and skill or who are adequately supervised.

2.20 Documentation of Collections

Documentation of museum collections should be undertaken according to accepted professional standards. Such documentation should include a full identification and description of each item, its associations, provenance, condition, treatment, and present location. Such data should be kept in a secure environment and be supported by retrieval systems to provide access to this information to museum personnel and other legitimate users.

2.21 Protection Against Disasters

Careful attention should be given to the development of policies to protect collections during armed conflict and other human-made or natural disasters.

2.22 Security of Collection and Associated Data

The museum should exercise control to avoid disclosing sensitive personal or related information and other confidential matters when collection data is made available to the public.

2.23 Preventive Conservation

Preventive conservation is an important element of museum policy and collections care. It is an essential responsibility of members of the museum profession to create and maintain a protective environment for the collections in their care, whether in storage, on display, or in transit.

2.24 Collection Conservation and Restoration	The museum should carefully monitor the condition of collections to determine when an object or specimen may require conservation-restoration work and the services of a qualified conservator-restorer. The principal goal should be the stabilization of the object or specimen. All conservation procedures should be documented and as reversible as possible. All alterations should be clearly distinguishable from the original object or specimen.

MUSEUM COLLECTIONS & RESEARCH

3.5 Research	Research by museum personnel should relate to the museum's mission and objectives and conform to established legal, ethical, and academic practices.
3.6 Destructive Analysis	When destructive analytical techniques are undertaken, a complete record of the material analysed, the outcome of the analysis, and the resulting research, including publications, should become a part of the permanent record of the object.
3.7 Human Remains and Materials of Sacred Significance	Research on human remains and materials of sacred significance must be accomplished in a manner consistent with professional standards and consider the interests and beliefs of the community, ethnic or religious groups from whom the objects originated, and where these are known.
3.8 Retention of Rights to Research Materials	When museum personnel prepare material for presentation or to document a field investigation, there must be a clear agreement with the sponsoring museum regarding all rights to such work.
3.9 Shared Expertise	Members of the museum profession have an obligation to share their knowledge and experience with colleagues, scholars, and students in relevant fields. They should respect and acknowledge those from whom they have learned and should pass on such advancements in techniques and experience that may be of benefit to others.
3.10 Co-operation Between Museums and Other Institutions	Museum personnel should acknowledge and endorse the need for cooperation and consultation between institutions with similar interests and collecting practices. This is particularly so with institutes of higher education and certain public utilities where research may generate important records of collections for which there is no long-term security.

Glossary

Conservator-Restorer

Museum or independent personnel qualified to undertake the technical examination, preservation, conservation, and restoration of cultural property.

Cultural Heritage

Any item or concept considered of aesthetic, historical, scientific, or spiritual significance.

AIC Code of Ethics and Guidelines for Practice (2003)

https://www.culturalheritage.org/about-conservation/code-of-ethics

AIC definitions of Conservation Terminology

Conservation:
The profession devoted to the preservation of cultural property for the future. Conservation activities include examination, documentation, treatment, and preventive care, supported by research and education.

Examination:
The investigation of the structure, materials, and condition of cultural property, including the identification of the extent and causes of alteration and deterioration.

Documentation:
The recording in a permanent format of the information derived from conservation activities.

Treatment:
The deliberate alteration of the chemical and/or physical aspects of cultural property, aimed primarily at prolonging its existence. Treatment may consist of stabilization and/ or restoration.

Stabilization:
Treatment procedures intended to maintain the integrity of the cultural property and minimize deterioration.

Restoration:
Treatment procedures intended to return cultural property to a known or assumed state, often through the addition of non-original material.

Preventive Care (Preventive conservation):
The mitigation of deterioration and damage to cultural property through the formulation and implementation of policies and procedures for the following 10 Agents of Deterioration: appropriate environmental conditions; handling and maintenance procedures for storage, exhibition, packing, transport, and use; integrated pest management; emergency preparedness and response; and reformatting/ duplication.

Cultural Property:
Objects, collections, specimens, structures, or sites identified as having artistic, historic, scientific religious or social significance.

Preservation:
The protection of cultural property through activities that minimize chemical and physical deterioration and damage and that prevent loss of information content. The primary goal of preservation is to prolong the existence of cultural property.

Conservator:
A profession whose primary occupation is conservation and who through specialized education, knowledge, training, and experience, formulates and implements all the activities of conservation in accordance with an ethical code such as the AIC Code of Ethics and Guidelines for Practice.

AIC Guidelines for Practice

EXAMINATION AND INVESTIGATION

16 Justification:

Careful examination of cultural property forms the basis for all future action by the conservation professional. Before undertaking any examination or tests that may cause a change to cultural property, the conservation professional should establish the necessity for such procedures.

17. Sampling and Testing:

Prior consent must be obtained from the owner, custodian, or agent before any material is removed from a cultural property. Only the minimum required should be removed, and a record of removal must be made. When appropriate, the material removed should be retained.

18. Interpretation:

Declarations of age, origin, or authenticity should be made only when based on sound evidence.

19. Scientific Investigation:

The conservation professional should follow accepted scientific standards and research protocols.

PREVENTIVE CONSERVATION

20. Preventive Conservation:

The conservation professional should recognize the critical importance of preventive conservation as the most effective means of promoting the long-term preservation of cultural property. The conservation professional should provide guidelines for continuing use and care, recommend appropriate environmental conditions for storage and exhibition, and encourage proper procedures for handling, packing, and transport.

TREATMENT

21. Suitability:

The conservation professional performs within a continuum of care and will rarely be the last entrusted with the conservation of cultural property. The conservation professional should only recommend or undertake treatment that is judged suitable for the preservation of the aesthetic, conceptual, and physical characteristics of the cultural property. When non-intervention best serves to promote the preservation of the cultural property, it may be appropriate to recommend that no treatment be performed/ undertaken.

22. Materials and Methods:

The conservation professional is responsible for choosing materials and methods appropriate to the objectives of each specific treatment and consistent with currently accepted practice. The advantages of the materials and methods chosen must be balanced against their potential adverse effects on future examination, scientific investigation, treatment, and function.

23. Compensation for Loss:

Any intervention to compensate for loss should be documented in treatment records and reports and should be detectable by common examination methods. Such compensation should be reversible and should not falsely modify the known aesthetic, conceptual, and physical characteristics of the cultural property, especially by removing or obscuring original material.

DOCUMENTATION

24. Documentation:

The conservation professional must produce and maintain accurate, complete, and permanent records of examination, sampling, scientific investigation, and treatment. When appropriate, the records should be both written and pictorial. The kind and extent of documentation may vary according to the circumstances, the nature of the object, or whether an individual object or a collection is to be documented. The purposes of such documentation are:

- to establish the condition of cultural property.
- to aid in the care of cultural property by providing information helpful to future treatment and by adding to the profession's body of knowledge.
- to aid the owner, custodian, or authorized agent and society, in the appreciation and use of cultural property by increasing understanding of an object's aesthetic, conceptual, and physical characteristics; and
- to aid the conservation professional by providing a reference that can assist in the continued development of knowledge and by supplying records that can help avoid misunderstanding and unnecessary litigation.

25. Documentation of Examination:

Before any intervention, the conservation professional should make a thorough examination of the cultural property and create appropriate records. These records and the reports derived from them must identify the cultural property and include the date of examination and the name of the examiner. They also should include, as appropriate, a description of the structure, materials, condition, and pertinent history.

26. Treatment Plan:

Following examination and before treatment, the conservation professional should prepare a plan describing the course of treatment. This plan should also include the justification for and the objectives of treatment, alternative approaches, if feasible, and the potential risks. When appropriate, this plan should be submitted as a proposal to the owner, custodian, or authorized agent.

27. Documentation of Treatment:

During treatment, the conservation professional should maintain dated documentation that includes a record or description of techniques or procedures involved, materials used and their composition, the nature and extent of all alterations, and any additional information revealed or otherwise ascertained. A report prepared from these records should summarize this information and provide, as necessary, recommendations for subsequent care.

28. Preservation of Documentation:

Documentation is an invaluable part of the history of cultural property and should be produced and maintained in as permanent a manner as practicable. Copies of reports of examination and treatment must be given to the owner, custodian, or authorized agent, who should be advised of the importance of maintaining these materials with the cultural property. Documentation is also an \important part of the profession's body of knowledge. The conservation professional should strive to preserve these records and give other professionals appropriate access to them when access does not contravene confidentiality agreements

The Japan Society for the Conservation of Cultural Property Established on July 8, 2008

https://jsccp.or.jp/abstract/regulate_08.html

Code of Conduct for Persons Involved in Cultural Properties

Cultural properties are tangible and intangible heritage created by people and nature with high artistic, historically or academic value. We must not only use this irreplaceable heritage shared by humanity in our own generations, but also preserve it for future generations. The purpose of the Society for the Conservation and Restoration of Cultural Properties is to develop and disseminate science and technology related to the preservation and utilization of cultural properties. In order to fulfill this purpose, members of the Japan Society for the Conservation and Restoration of Cultural Properties shall fulfill their responsibilities as experts and act with the awareness that they have a responsibility as a member of society for the safety and well-being of society, human health, history, culture, and the natural environment. In addition, we will spread understanding of the preservation of cultural properties through education and dissemination, and contribute to the development of this field.

Based on this recognition, the Society for the Conservation and Restoration of Cultural Properties hereby establishes a code of conduct and makes it a code to be observed by its members. At the same time, we believe that this code of conduct can be a code to be observed by those involved in the preservation of cultural properties in general.

1. Respect for cultural assets

The members of the Society for the Conservation and Restoration of Cultural Properties recognize that cultural properties are valuable heritage of humankind, and conduct surveys, research, disclosures, and conservation and restoration measures with respect for cultural properties.

2. Respect for the Value of Cultural Properties

Members of the Society for the Conservation and Restoration of Cultural Properties shall consider and select appropriate methods and materials so as not to impair the artistic, historical, or academic value of cultural properties when conducting surveys, research, public displays, conservation, and restoration procedures.

3. Ensuring safety

Members of the Society for the Conservation and Restoration of Cultural Properties shall select methods and materials used in surveys, research, disclosure, conservation, and restoration procedures that are safe for cultural properties and appropriate in consideration of human health and the environment.

4. Emphasis on the preservation environment

Members of the Society for the Conservation and Restoration of Cultural Properties recognize that the maintenance of the preservation environment is the most important for the long-term preservation of cultural properties, and strive to realize a better preservation environment for cultural properties.

5. Self-improvement

Members of the Society for the Conservation and Restoration of Cultural Properties shall endeavor to maintain and improve their specialized knowledge, abilities, and skills through opportunities such as academic activities, education, and training, and shall do their best to carry out such activities.

6**. Cooperation with experts**

The members of the Society for the Conservation and Restoration of Cultural Properties are aware that the preservation of cultural properties is related to many fields such as art, history, culture, and natural science, and actively seek the cooperation of other experts in surveys, research, disclosure, and conservation and restoration procedures.

7. **Relationship with others**

The members of the Society for the Conservation and Restoration of Cultural Properties treat other experts with integrity and respect, appropriately criticize the achievements of others, humbly listen to criticism from others, and strive to develop this field.

8. Creation, preservation and publication of records

Members of the Society for the Conservation and Restoration of Cultural Properties shall prepare appropriate records and reports while ensuring reliability, and strive to preserve and manage them appropriately and publish them in surveys, research, and conservation and restoration measures.

9. **Compliance with Laws and Regulations**

Members of the Society for the Conservation and Restoration of Cultural Properties shall comply with relevant laws and regulations in surveys, research, disclosure, and conservation and restoration measures. We will respect the intellectual achievements and intellectual property rights of others and will not infringe on them.

10. **Compliance with the Code of Conduct**

Members of the Society for the Conservation and Restoration of Cultural Properties comply with this Code of Conduct and encourage other members to follow it.

*Translated by Vanessa Bray and Mie Ishii

2 Planning for Textile Conservation

The current direction in conservation worldwide is to collaborate with other specialists and conduct interdisciplinary research. It is important to understand the concerns and needs of other professionals when making decisions about how to care for historic textiles. Collaboration, discussion, and the sharing of information with professionals from other disciplines will contribute to finding solutions and advancing the practice of archaeological conservation and research.

An archaeological textile is different from an ethnographic textile in that the former is a manmade product from the past, which was at some point lost, abandoned, or intentionally buried. The condition of these preserved textiles depends on their reaction to the surrounding environmental conditions. Since textiles are organic matter, they disintegrate in the earth, but there are also many cases where archaeological textiles have been excavated from environments of extreme dryness, permafrost, and waterlogged conditions. Changes in environmental conditions due to excavation accelerate the material degradation of these textiles, both physically and chemically, making them vulnerable. Careful handling, packing, storage, and display are crucial for the survival of the material as an artefact. Without such care, the material would be reduced to nothing more than powdered fibre.

Conservation techniques to consolidate fragile fibres using adhesives were first developed around the 1950s. While there are some valid adhesive treatments, theoretically reversible adhesives, when aged, have been found to not be reversible or re-treatable, thus causing problems. Past consolidation treatments can interfere with future examination and scientific analysis.

With the evolution of preventive conservation in the 1980s, conservation methodologies avoiding the use of adhesives, such as various mounting and anoxia methods, have been developed. Fewer adhesive treatments are now practised on historic textiles and treatments using adhesives are considered a last resort. It is now widely acknowledged that the physical longevity of historic textiles should be based on preventive care.

Conservation science developed around the 1990s as a result of the advancement of analytical technology. Archaeologists can now use scanning electron microscopy to identify pollens which can be relevant for discovering the season of burial, burial culture, and vegetation distribution. Costumes along with plants have been excavated as burial goods. Carbon 14 dating can be conducted on textiles with a very small fibre sample (approximately 0.01g). However, even a small amount of new fibre contamination may affect accurate readings. To be sensitive to such issues it is important to review concepts and methodologies of conservation practice, such as cleaning, support and restoration treatments which may include the removal of materials and the addition of new materials.

In conserving historic textiles, the primal activity is to understand what is to be preserved and to do so, a thorough investigation is necessary. To understand the textile within its context, both the material continuity of the textile as well as intangible and unseen concepts, such as the culture, philosophy and beliefs of the maker and user, should be respected and preserved[1]. After this initial research, it is important to consider how to preserve the textile and assess what actions should be taken to slow the speed of deterioration.

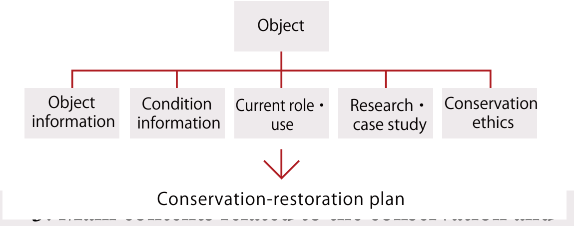
1. Guidelines for conservation practice

Conservators and conservation scientists often face issues when making decisions about the conservation of an artefact that is not straightforward. When a specific problem arises, judgment will become difficult if there is no standard to judge against. It is important to be able to compare whether the practice is suitable or acceptable within the technical field.

The American Institute for Conservation (and Foundation for Advancement in Conservation) of Historic and Artistic Works was one of the first independent organizations of conservation professionals to produce a written standard of practice for its members. The first draft was published in 1964 in Studies in Conservation. The AIC Code of Ethics and Guidelines for Practice was issued in 1967 and with several amendments, the current version was accepted in 2003. This document has been referred to by many national committees of conservation around the world when producing their standards, including The Japan Society for the Conservation of Cultural Property.

2. Formulation of preservation plans

In the practice of preserving the collection, a guiding plan is the most important part of conservation management in the museum. In doing so, it is necessary to collect information about the work, diagnose its condition, and through research understand how the past and the present are related, investigate the role and utilization of the present work, know the related research between the past and the present, and consider conservation ethics.



restoration of textiles

- Survey and recording of works (shapes, dimensions, material techniques, historical descriptions, photographs)
- Condition investigation and recording (location, condition, factors, photos)

- Object examination and documentation
- Condition examination and documentation
- Conservation proposal/ plan
  (Consider collection policy, the social role of the object, case studies & research)
- Conservation treatment
- Conservation report
- Education and research
- Exhibition and display (mounting, environmental control, handling etc.)
- Transportation (packing, courier, condition reports for loans)

4. Textile conservation treatment

The primary aim of conservation treatment is stabilization. Treatment of an artefact can be classified into interventive/ remedial treatment and non-interventive/ passive treatment according to the degree of direct intervention to the object. 'Restoration' is an interventive treatment which includes procedures to return the artefact to its assumed original or ideal state.

① **Dismantling / Reassembling methods**

② **Reshaping methods**
- Humidification (misting, steaming)
- Heat application (ironing)

③ **Cleaning methods**
- Surface cleaning
- Wet cleaning
- Organic solvent cleaning (dry cleaning)
- Enzyme cleaning
- Bleaching

④ **Supporting methods**
- Dyeing support fabrics and threads
- Mounting (physical support with a firm material)
- Covering/overlay (fabric support from the obverse side)
- Backing (fabric support from the reverse side)
- Sandwiching (fabric support from both sides)

⑤ **Method of attachment**
- Stitch support (physical treatment)
- Adhesive support (chemical treatment)
- Adhesive consolidation (chemical treatment)

⑥ **Preventive conservation methods**
- Material testing
- Storage methods
- Display methods
- Transportation methods
- Integrated pest management methods (IPM)

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3 Examination, Documentation and Photography

ICOM *Code of Ethics for Standard Practice* [1] states that the responsibility of museum professionals, regarding the care of a collection, is to ensure that its collection and associated materials are passed on to the future generation in as good and safe condition as practicable (2.20). Each object should be documented, and the data should be easily accessible. Preventive conservation needs to be regulated and should follow a conservation plan. Artefacts should be carefully monitored and in cases where conservation/restoration is required, treatment should be carried out to stabilize the object. All steps taken must be documented and changes to an object should be executed in a method where they can be differentiated from the original.

1. Handling

It is important to wear surgical gloves without powder when handling a textile[5]. When using bare hands, wash well before and after handling. To protect the textile and the handler, wearing a lab coat, mask, and goggles is highly recommended.

A textile must always be supported with both hands. Place the textile on a handling tray or a supporting container. Materials for the container or tray should be an inert substance such as archival cardboard, cotton board, acrylic sheets (Perspex®), thick polyester film (Mylar®, Melinex®, Lumirror®), and polypropylene board[6]. When designing a container for a specific textile, 10 cm should be added to the width and length of the textile, with an additional 5 cm (length of the thumb) as a handling edge around the textile to avoid touching it directly.

2. Examination and investigation

Visual examination of the textile is the first step in a conservation procedure. The conservator should identify the overall features, size, fabric structure, materials, and technique, and diagnose the condition of the artefact. Examination using special lights, such as ultra-violet (UV) and infrared (IR) may provide additional information about the material, make-up, and condition of the artefact. Any papers and documents, such as excavation records, related to the textile may provide further information and should be documented.

3. Documentation

Associated object records, such as filed reports and conservation reports etc. are important documents for a museum archive. The aim of keeping a record is to document the results of object examination and add any museum activity including conservation treatments regarding the object which will become part of the object's history. The record should be updated whenever any actions, such as conservation, display, examination, or loan, are performed. Curatorial and conservation departments in museums often keep separate records. However, many museums are now combining information held in several departments into one digital database to share collection information. The following list is an example of documentation subjects.

4. Documentation subjects

① **Object information**

Object ID, object name, classification (object type), collection date and method (given / acquired/ bequeathed/ loan), provenance, date of manufacture, place, culture, dimensions, object description (colour, design and layout of patterns), ancient repair, ancient use, present role of the object, present use/ future use of the object, photograph/ drawing (overall obverse, reverse, detail), level of historical value, location of storage, copy of any publications, copy of information on similar objects

② **Material and technique**

Present colour, fabrication method, fabric structure, fibre, yarn make-up, weave count, selvedge, seam, fringe, dye, finishing, handle (touch), method of analysis, instrumental analysis report

③ **Condition information**

Condition description (physical and chemical assessment, soiling), past conservation treatment, condition diagram, photograph, drawing, documents on past treatment

④ **Conservation proposal (plan), reasons for treatment**

⑤ **Conservation report**

Tools and materials, process, photograph (before, during and after conservation)

⑥ **Preventive conservation**

Handling, storage, display, illumination, loans, transportation, environmental requirements

⑦ **Information to be passed on to the future**

5. Photography

Photography aims to identify and document the current state of an object. Photographs taken with suitable lighting and camera settings can reveal a wealth of information such as the object's construction, material, fabrication, colour, and condition. Photographs are useful to document and differentiate old damage from damage that has recently occurred. Digital cameras allow high-resolution images, cost-effectiveness, and suitability for storing the image in a digital database. The image recording device for a digital camera is an image sensor. The photographic mechanisms of a film camera and a digital camera are different, but the same terminology is used in both types of photography. There are three points which determine exposure; shutter speed, ISO sensitivity and aperture. These are explained in the following text.

5.1 Photographic methods used in archaeological textile documentation

1. Daylight photography[2]
2. UV reflectance light photography[3] (fluorescence of dyes etc.)
3. IR photography[4] (carbon materials, pigments)
4. X-ray photography[5] (inorganic materials)

Fig. 3.1 Salt bag, front, overall photograph
20th century, Armenia, Private collection.

Fig. 3.2 Salt bag, reverse side, overall photograph.

Fig. 3.3 Salt bag, detail.

Fig. 3.4 Salt bag, detail

5.2 Image composition

An overall photograph should include the object's ID, date, ruler, stage of conservation (before, during or after conservation), colour and grey scale. It is preferable to include a ruler in a detailed or enlarged photograph. The colour grey (around 20% grey) is recommended for a consistent neutral background.

1. Overall obverse and reverse
2. Detail

5.3 Shutter speed SS

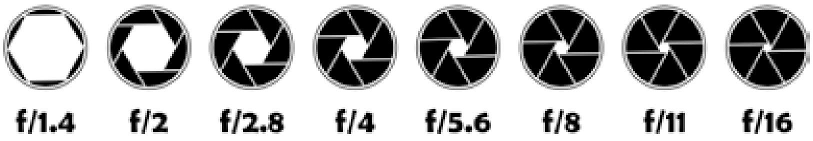
Shutter speed (SS) is the length of time the shutter is open and the film or image sensor is exposed to light through the lens. When the camera is mounted on a tripod and a lamp is used to photograph a still object, SS is determined by the aperture (f). A release or timer should be used for this type of photography.

5.4 ISO sensitivity

The light sensitivity of a film is described by the ISO number, such as ISO 100, ISO 200, ISO 400, ISO 800 etc. The larger the number, the higher the light sensitivity of the film becomes but with this increase the image will also become rougher. The same principle applies to digital cameras. ISO 100-200 is suitable for taking photographs of flat textiles under daylight, whereas ISO 800 is preferable in dark places, or for fast-moving objects which need to be taken with a fast shutter speed.

5.5 Aperture f

Aperture (f) is a device used to control the amount of light passing through the lens. The size of the open area is called the f-stop and each stage is numbered. The larger the number, the smaller the aperture becomes, providing a wider depth of field. The smaller the f-number, the narrower the object focus becomes. Depth of field is the length at which the targeted area remains in focus. When photographing a flat textile at a near distance, the aperture is set at f 16-22.



Shallow depth of field = narrow object focus

Deep depth of field = wide object focus

Fig. 3.5 Digital camera

Fig. 3.6 Light meter

Fig. 3.7 Xrite® colour checker

Fig. 3.8 Spirit level

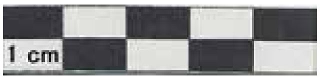


Fig. 3.9 Scale

6. Daylight photography[6-7]

Daylight is the spectral distribution of 360-830 nm which can be observed by the human eye. To photograph objects within this spectrum, the use of a white lamp (tungsten, white fluorescence, or white LED) with a colour temperature of around 3200K is recommended. The lamp should be mounted on a light stand. When using a digital camera, the white balance should be set at the same colour index as the lamp used. A non-UV emitting lamp is preferable but applying a UV cut film in front of the light bulb can also cut UV radiation. If lamps are unavailable, a relatively good image can be taken near a north-facing window in the morning light (in the northern hemisphere) or a south-facing window (in the southern hemisphere). When using a tripod, ISO sensitivity is set at ISO100, 200 or 400. Use an incident-light meter to achieve balanced lighting. The light meter should be set to the same ISO rating as the camera to measure the exposure correctly.

6.1 Tools and equipment

Digital camera, level, daylight lamp, light stand, light meter (auto-meter), background paper (grey paper), ruler, colour checker, object ID, date, stage of conservation, tripod, or photography stand.

6.2 Method

1. Lay down the grey background paper.
2. Secure the camera to a tripod or a photographic stand and make sure that it is parallel to the platform.
3. Place the lamps on either side of the object at a ∠ 45°angle. The height of the lamp should be about the same height as the camera.
4. Set the white balance of the digital camera to the colour index (temperature) of the lamp.
5. Set the ISO sensitivity of the auto-meter between ISO100 to 400 and make sure that the light is evenly distributed on the object.
6. Set the ISO sensitivity of the camera and aperture f stop.
7. Set the shutter speed at auto or to the rate of the auto-meter.
8. Focus manually or automatically.
9. Use a self-timer or shutter release to take the photograph.

Fig. 3.10 Photography set up

7. UV reflectance light photography

Some materials absorb near UV radiation of around 250 -360 nm and emit fluorescence by excitation of the fluorochromes/particles. Consequently to this phenomenon, in textile conservation, UV light is often used to examine and record the fluorescence of dyes, mould, bacteria, sweat, and oil.

UV radiation is damaging to organic materials and thus UV photography is not practised as part of routine documentation. Instead, it is used mainly for examination records. Since UV radiation is also damaging to human health, especially to the skin and eyes, when conducting UV photography, long sleeve protective clothing, gloves and UV protective goggles must be worn. For the setup, mount the camera on a tripod and set the sensitivity at ISO 400 or 800. Two methods of conducting UV reflectance photography are described below.

7.1 Equipment

Use a special filter attached to a lens. Kodak Wratten 18A, Hoya U-340, Kenko U-360, and Toshiba UV-D are some examples of suitable filters. The photographer should wear dark clothes to avoid unnecessary reflection.

7.2 Method

Photography should be performed in a dark room using a UV lamp (254 - 365 nm). Mount the lamp on a light stand. Set ISO sensitivity at 400-800, f = 5.6, SS = auto, focus manually.

Fig. 3.10 Day light photograph

Fig. 3.11 UV photographs. The red fluorescence is safflower, the yellow is turmeric.

8. Infrared examination and photography

Near-infrared radiation of around 700-800 nm can permeate thin layers without scattering due to its long wavelength, thus enabling the photography of materials underneath the surface. In painting conservation, IR is often used to examine sketches made with carbon and is also applicable to textiles.

8.1 IR photography with a digital camera

A normal digital camera is equipped with a filter which lowers the level of IR sensitivity. Therefore, to take an IR photograph, the filter needs to be replaced with an IR permeable type filter. Digital cameras equipped with an IR photograph function (Pentax 645D, Mamiya ZD/ZD back, IR web camera) are also available.

Fig. 3.12 1R photography

8.2 Lamp

Use a daylight lamp which includes IR radiation or an IR lamp.

8.3 Filter

Glass filter KENKO PRO1D R72 (cuts out radiation below 720 nm) Gelatine filter FUJI Film IR78, IR80, KODAK Wratten 87C.

8.4 Processing images

An IR image can be converted into a black and white image using an image software program which helps to analyse and diagnose materials. Figures 3.13 and 3.14 show that inorganic and carbon colouring matter absorbs IR radiation, appearing in dark colours, which helps to speculate the type of colouring matter used to fabricate the textile.

Fig. 3.13 Day light photograph

Fig. 3.14 IR photograph indicates where the dyes brown, red, and green permeated IR radiation.

Reference

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2. Christel M. Baldi and Kathryn A. Jakes. 2007. Photographic methods to detect colourants in archaeological textiles, *Journal of Archaeological Science* 34, pp. 519-525.
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Joanne Dyer, Giovanni Verri and John Cupitt. 2013. *Multispectral Imaging in Reflectance and Photo-induced Luminescence Modes: A User Manual*. The British Museum.

1) Object ID	2) Name of object	3) Object image or diagram
4) Classification	5) Dimensions	
6) Collection date and method (given / acquired/ bequeathed/ loan)	length width height cm / mm	
7) Provenance	26) Condition	
8) Date	27) Amount remaining	
9) Place	28) Discoloration	
10) Culture	29) Soiling	
11) Description / characteristic	30) Creasing	
12) Ancient use	31) Physical damage	
13) Ancient repair	32) Fibre degradation	
14) Fabrication method felted looped (looping) knitted plaited (sprang) woven	33) Level of historic value	
15) Fabric structure	34) Expected future use/ role	
16) Weave count (woven) per cm	35) Urgency of treatment	

17) Element	18) Color	19) Fiber	20) Dye	21) Mordant	22) Make-up
warp					
weft					

	36) Conservation plan	
	37) Environmental requirements	40) Transportation requirements
23) Decoration (embroidery, bead work, painted surface etc)	38) Storage location	41) Examination and photographic record/ location of record
24) Construction (sewing)	39) Method of storage and size	DL UV IR X-ray
25) Sampling and analysis information (attach to this file)	42) Note, references	

43) Date

44) Name

Chapter 2

Investigation and Analysis of Textiles

Investigation and Analysis of Textiles

4 Technical Analysis of Fabric Structures

Documenting the technical features of an ancient fabric greatly contributes to knowledge in the field of textile study. Incorrect information may be perpetuated in published reports, so it is important to document object information accurately. The Primary Structure of Fabrics (1966)[1] by Irene Emery is the principal reference used when documenting and cataloguing the fabric structures of ancient and historic textiles. Emery conceptualized fabric structures and used the term element to describe their fundamental component. This chapter introduces the basic classification of fibres and fabric structures of up to two elements (one warp and one weft) based on Emery's study. Compound structures (advanced weave with more than one warp and weft) are not discussed here. Since weaving terminology is specialized, there may be areas of mistranslation, but the basic principles are outlined in the following section.

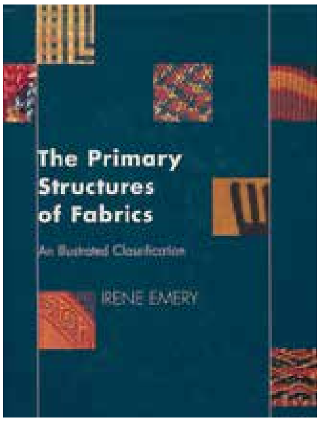


Fig. 4.1 The Primary Structures of Fabrics 1966

1. Examination of fabrics with magnification/ microscopy

A hand-held lens of around 30x magnification and a thread counter are the basic tools for examining fabrics. Stereomicroscopes, light microscopes and scanning electron microscopes (SEM) are available for a more detailed observation of the physical characteristics of a fabric. Stereomicroscopes allow magnification of up to several hundred times. The light is projected from above the sample and light reflectance is used to observe colour and surface information. A light microscope allows magnification of up to several thousand and uses transmitted light from below the sample to observe the colour, surface, and inner information. SEM allows magnification of up to several million. The sample is irradiated with an electron beam from above and the reflected electrons are computerized into an image to observe surface information. For textile examination purposes, in addition to a magnifier, a stereomicroscope and a light microscope are efficient.

2. Classification of fabric structures for fabric analysis

The property of a fabric is determined by the fibre, yarn makeup and the fabric structure. Understanding the classification of fabrics is important for fabric analysis. In classifying the structures of fabrics, a primary distinction must be made between structures which are composed directly of fibres or fibrous material that are felted (adhered and matted together) and those that are produced by ordered interworking of prepared elements (interworked elements).

In felted fibres, there are no distinguishable intervening stages between the initial loose fibre or natural plant section and the final fabric. The fibre itself is the component of the fabric structure.

Interworked structures involve at least three stages: (1) loose fibres or fibrous materials, (2) twisting of fibres into elements (yarns) and interworking them to form a (3) fabric. It is the order and way in which elements (yarns) are interworked that provide the bases on which interworked structures are classified.

3. From fibre to fabric

3.1 Felted fibres

Fibres ⇒ Fabric, non-woven

①Natural plant forms

- Beaten bark cloth ⇒ inner bark of a tree, moistened and pounded
- Papyrus – flattened strips of longitudinal fibre (reed)

②**Agglomerated fibres**

- Felt ⇒ moistened, kneaded, pounded, and rolled animal fibre
- Paper ⇒ flattened web of enmeshed plant fibre

3.2 Interworked elements

Fibres ⇒ Element (yarn) ⇒ Interworked structure

- Linking
- Interlinking
- Looping (knotting)
- Interconnected looping (knitting)
- Interlacing (weaving, plaiting)
- Twining
- Twisting
- Wrapping


Fig. 4.2 Papyrus


Fig. 4.3 Felt and paper (non-woven)


Fig. 4.4 Cotton and cotton yarn

4. Yarn: structural make-up

A yarn is the basic element of a constructed fabric structure, and it is made up of either filaments or staple fibres. Staple fibres are arranged and twisted to make up long yarns. Filaments may be used without twisting. Twisting two or more yarns together enhances the strength of the yarn[3].

4.1 Filament fibres

①Single (not spun)

②Combined (unit)

③Twisted together (spun, plied)

4.2 Staple fibres

①Single (not spun)

②Combined (unit)

③Twisted together (spun)

- Single
- Combined
- Plied
- Re-plied


Fig. 4.5 Flax and linen yarn


Fig. 4.6 Wool and wool yarn


Fig. 4.7 Cocoon and silk filament

Fig. 4.8 Spining with a drop spindle

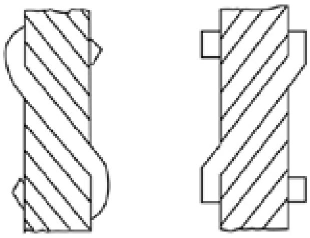


Fig. 4.9 Right twist (S \) Left twist '(Z /)

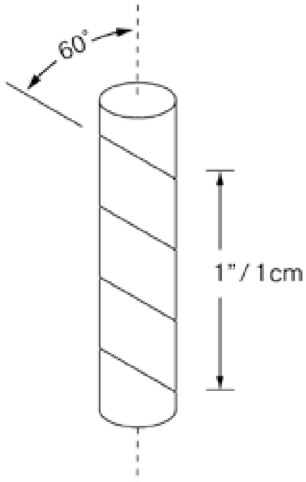


Fig. 4.10 Twist angle and the number of twists in 1cm or 1 inch.

4.3. Single yarn (JIS L 0104)[4]

Single yarn refers to the simplest continuous bundle of fibres. (1) Spun yarn is made by fixing many discontinuous fibres by twisting. (2) Filament yarn composed of one or more long fibres (filaments). There may or may not be twisted. A thread consisting of one filament is called a monofilament yarn, and a thread consisting of two or more filaments is called a multifilament yarn.

4.4 Alignment thread

A matching yarn is a yarn consisting of two or more single yarns without twisting.

4.5 Miscellaneous yarn

A yarn is made by combining two or more single yarns in a single-joint yarn operation. In the case of two, it is twin yarn (two-thread), and in the case of three, it is three-thread.

4.6 Twisting direction

The twist inserted at the stage of single yarn is called "lower twisting", and the twist inserted after the joint yarn is called "upper twisting".

- "S twisting" or right twisting (twisting by right rotation).
- "Z twisting" or left twisting (twisting by left rotation).
- A single thread is noted as "S" or "Z".
- An example of a notation of a yarn that is made up of two single yarns, each twisted in an S direction and plied into one in a Z direction is "S2Z".

4.7 Twisting strength

Weakly twisted yarn (sweet twist) is generally 100~300 times/m, and strong twisted yarn is 1000~3000 times/m. The strength of the twist of the thread looks at the number of twists and the angle of twist between 1 inch (2.54 cm) or 1 centimetre. An angle of around 10 ° is weakly twisted, around 25 ° is medium twisted yarn, and 45 ° or more is strong twisted yarn. Since the fibres are condensed, the strong twisted yarn has a large tensile strength.

4.8 Weaving density (weave count)

Weaving density or weave count refers to the number of warp or weft threads in a fabric per centimetre or inch (2.54 cm). The weaving density is measured by applying a measure to the fabric and observing it closely with a magnifying glass or linen tester.

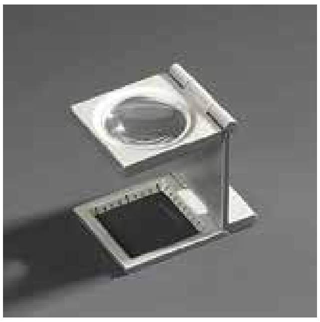


Fig. 4.11 Thread counter (10x)

Fig. 4.12 Digital microscope

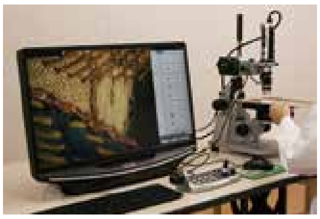


Fig. 4.13 High resolution digital microsicope

Fig. 4.14 Making models with cardboard frame aids understanding of fabric structures.

5. Element interaction

The classification of fabric structures is based on the basic organization created by the interaction of elements[5]. Checking the number of elements or sets of elements from which the fabric is formed is the basis of the histological analysis of the fabric.

Element: a component or unit of the structure that makes up an interworked fabric.

Set of elements: refers to an element that is a collection of parts that are all used in the same manner.

5.1 Single elements

- **One single element**

A structure is made up of a single element by knotting, looping, or twining.

e.g., knitting, needle lace

- **Two single elements**

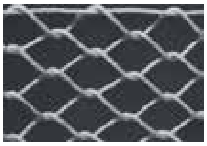
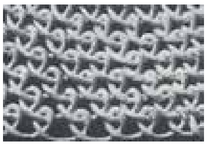
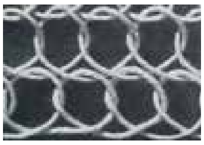
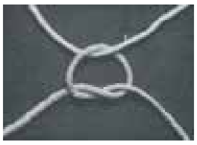
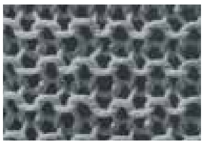
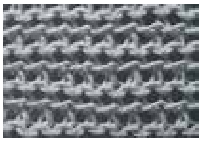
A structure is made up of two single elements by knotting, looping and twining.

- **One set of elements**

A structure is made up of one set of elements as a group.

e.g., plaiting, sprang

Table 5.1 One single element and two single elements[5]

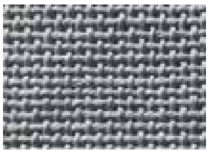
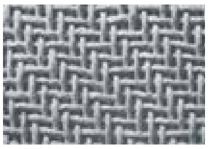
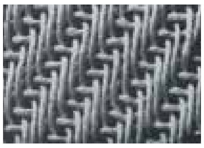
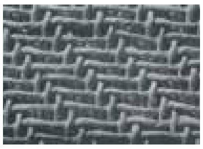
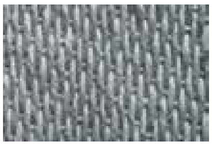
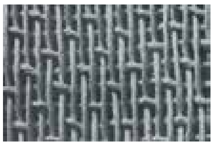
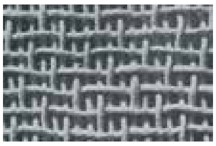
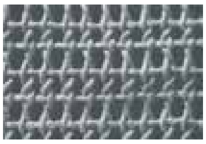
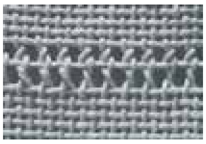
① Linking			
① Simple looping			
	1. Looping	2. Connected looping	3. Looping (two single element)
③ Interlooping			
	1. Vertical（knitting）	2. Vertical and horizontal （crochet）	

5.2 Two sets of elements

The organization is composed of one set of elements by an aggregate of threads. For example, plain weaves are composed of two sets of elements: warp and weft. There are four basic woven structures, plain weave, twill weave, satin weave and gauze weave.

Fig. 4.15 Paper weaving aids understanding of woven structures.

Table 5.2 Four basic structures of woven fabrics[6]

① Plain weave			
② Twill weave			
	2/2 Twill ↖	4/1 Twill ↗ Face	1/4 Twill ↖ Reverse
	Notation：2/2、3/1, The number of threads exceeding the weft / the number of weft threads being overtaken by the warp		
③ Satin weave			
	4/1 Satin	4/1 Satin (enlarged) Face	1/4 Satin (enlarged) Reverse
④ Gauze weave			
	1/1 gauze weave	Plain weave and gauze weave	

5.3 Composite fabric structure with supplementary warps and wefts

A fabric structure can be elaborated by additional warps and wefts.

- Continuous supplementary weft.
- Discontinuous supplementary weft.
- Continuous supplementary warp.
- Discontinuous supplementary warp.

References

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3. Ibid.
4. JIS (Japan Industrial Standard) L0104:2000 Designation of yarns by tex system. Equivalent to ISO 1139 :1973 Textiles: Designation of yarns.
5. Op.cit. 1, pp. 30-34, 40.
6. Op.cit. 1, pp. 76, 93, 108-110, 181.

5 Fibres

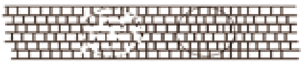


Fig. 5.1 Amorphous and crystalline regions of a fibre

Fine, flexible, and compact fibres are suitable for fabric materials. Fibre is the smallest element of fabric and can be classified into natural and synthetic types. Within natural fibres, there are plant-origin cellulose types and animal-origin protein types. Among synthetic fibres, regenerated and semi-regenerated fibres are derived from natural sources, and synthetic fibres are made by synthesizing chemicals from mineral origins. Staple fibres are those with short-length and long-length fibres called filaments.

The polymers of fibres form "crystalline regions" and "amorphous regions" on a micro-scale. For the same molecular weight, crystalline portions are harder and have higher melting points. Amorphous portions are softer and have lower melting points. It is thought that the strength, elongation, and dyeing properties of fibres depend on amorphous regions, as well as potential sites for fibre deterioration, due to the weaker molecular bonding in these regions[1].

1. Classification of fibres

1.1 Natural Fibres

Plant (cellulose)

- Seed fibres (cotton, kapok)
- Bast fibres (flax, jute, hemp)
- Leaf fibres (sisal, banana)
- Bark fibres (cedar)

Animal (protein)

- Secreted filament (silk)
- Hair fibres (wool-sheep, goat, camel)

Mineral (inorganic)

- Asbestos

1.2 Regenerated and synthetic fibre

Regenerated fibres

- Cellulosic fibres (viscose rayon, cupra)

Semi regenerated fibers

- Cellulosic fibres (acetate)
- Protein fibres (promix)

Synthetic fibers

- Polyamide fibres (nylon)
- Polyacrylonitrile fibres (acryl)
- Polyester fibres (polyester)

Inorganic fibres

- Glass

Metal fibres

- Glass, metals (gold, silver, steel etc.)

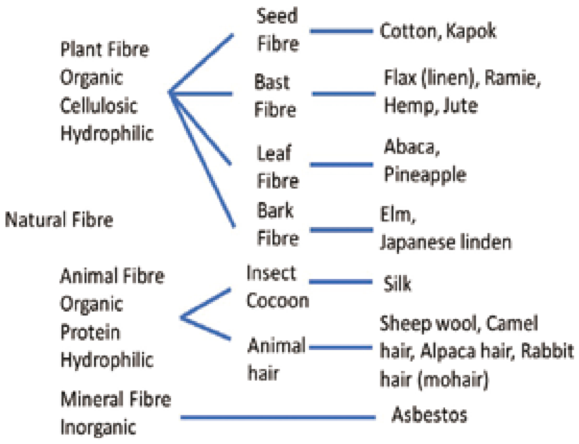


Fig. 5.2 Classification of natural fibres

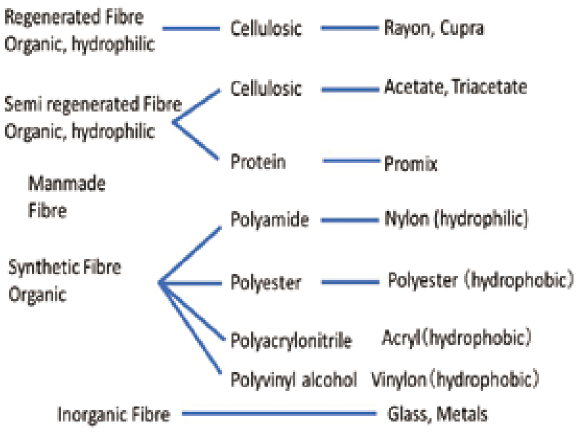


Fig. 5.3 Classification of manmade fibres

2. Natural cellulose fibres

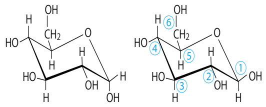


Fig. 5.4 β -D-glucose (right)
α -D-glucose (left)

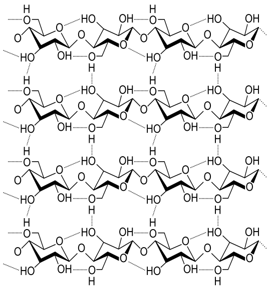


Fig. 5.5 The dotted line represents the hydrogen bonds of the cellulose fibre.

The main component of fibres derived from plants is cellulose. Cellulose is a polymer of β -D-glucose and is represented by the molecular formula $(C_6H_{10}O_5)n$. The molecules of β -D-glucose are bonded at the 1st- and 4th-positions forming a linear polymer. When cellulose molecules are in proximity in a parallel manner, a force of attraction acts between molecules and forms hydrogen bonding and becomes a large structure[2] (Figure 5.5).

Cellulose has a moisture content of 60-120% and swells due to absorbing water. This can be attributed to the arrangement of the hydroxyl groups (–OH). If the alignment of cellulose molecules is random and –OH groups are not rigidly structured, the force of attraction of the water molecules has a stronger effect and the water absorption properties of the fibres increase. When heated, cellulose starts to decompose at 150°C. Cellulose is electrically neutral but when bleached by light/UV radiation it generates carboxyl groups (–COOH). The carboxyl groups become $-COO^-$ in water, which produces a negatively charged surface facilitating bonding to cations[3].

Fig. 5.6 Cotton fibre is a seed fibre.

Fig.5.7 Cotton fibre is twisted. 400x (CAMEO)

Fig.5.8 Fibril layers of cotton

2.1 Cotton[4]

Cotton (*Gossypium* spp.) is a perennial herbaceous plant, the fibres of which are produced by the growth of the seed epidermal cells, with one fibre consisting of a single cell. When forming yarns, seeds are removed from fibres, and the fibres are scutched, un-tangled, combed and then spun. Cotton has been grown since ancient times in India, Africa, and America, and arrived in Japan via China in the 16th century.

By bundling large numbers of cells in parallel, micelles are formed, and helical fibre layers known as fibrils are produced. Due to this structural form, cotton can be easily stretched. Cotton fibres are ribbon-like and have a twisted shape. This twisting improves fibre cohesion, facilitates spinning, strengthens the yarn, and imparts elasticity. In the cross-section of cotton fibre, there is a hollow portion known as a lumen, which facilitates the inclusion of air, and swelling of the fibre upon absorption of water. Among plant fibres, cotton fibres contain the highest purity of natural cellulose.

The composition of cotton fibre is 94% cellulose, 1-1.5% protein, 0.1% pectin, 0.5 % waxes, and 0.2% colourants. Cotton fibres can be white, cream, brown, or green, and can range in length from 40-65 mm long to as short as 25 mm or less. Longer fibres tend to be finer.

Cotton fibres absorb water vapour in the air due to the presence of hydroxyl (–OH) groups in cellulose molecules and reach a state of equilibrium with the water vapour. New cotton fibres contain 8.5% of moisture and are hydrophilic. When swollen by absorption of water, cotton fibres have increased plasticity and improved adsorption of dyes and chemicals.

When heated, cotton fibres start to decompose at 150°C. The maximum ironing temperature of cotton is 180 °C. When irradiated with light, cotton fibres produce oxycellulose and decompose. Cotton fibres exhibit low resistance to acids, undergoing deterioration in strength and elongation, followed by hydrolysis when exposed to elevated temperatures for lengthy periods. Cotton fibres exhibit resistance to alkalis and are not affected by weak alkaline solutions. Therefore, when cotton fabrics are degummed using alkaline agents, impurities are removed, and almost pure cellulose is obtained. However, cotton fibres exhibit low resistance to strong alkalis, and swell in aqueous solutions, meaning that their twisted shape is lost, and the lumen is reduced in size. With these properties in mind, treating cotton fibres with alkaline agents to make the fibres round and smooth on the surface, thereby imparting a lustre to the fibres, is known as "mercerization". A lustrous cotton embroidery yarn is an example of this type of chemical treatment. These types of threads have been used instead of silk yarn as materials for restoring tapestries in textile conservation.

Acidic environments should be avoided when storing cotton-based historic textiles. Storing such artefacts in chests or on shelves made of wood, in cardboard packaging that emit acids, or wrapping them in commercially available tissue paper (acidic), just because it is soft, is not recommended. It is best to wrap cotton textiles in pH-neutral paper or, in cases where acidity is already advanced, in paper with an alkaline buffer to neutralize the acidification.

2.2 Flax[5]

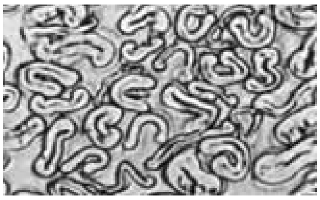


Fig.5.9 Cross section of cotton fibres. In the centre is a hollow lumen. (AATCC)

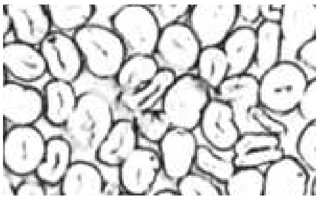


Fig.5.10 Mercerised cotton forms a round shape resulting in lustre (AATCC)

Flax (*Linum usitatissimum* L.) is an annual herbaceous plant with stalk bast fibres. It is native to Western Asia and is grown in relatively mild regions in Africa, India, Europe, America, and China. When processed into yarns or fabrics flax is known as linen. While the plant is growing, a woody section forms in the inner part of the stalk and epidermal cells form in the outer parts. Fibres overlay in a lengthwise direction and bundles are formed due to agglutination by pectin. The resulting cellulose molecules of the flax fibres are aligned in an almost perfectly parallel manner. The outer bast fibres can be mechanically separated from the inner woody part. The composition of the fibres is 90-92% cellulose, 4% lignin, and pectin. Flax fibres have a nodular shape, thick fibre cell walls, and a lumen with a narrow centre. They are pale brown in colour and become lustrous and white when degummed and bleached. On average, flax fibres have a length of 25-30 mm and a width of 15-25 μ m.

To extract the fibres, the stalks are first dried. In the past pectin, which agglutinates the fibres, was removed using fermentation by immersing the fibres in

Fig.5.11 Flax plant

Fig.5.12 Flax fibre 400x (CAMEO)

water but is now industrially removed using chemicals. This process is known as retting. Next, the woody part is subjected to breaking, scutching and hacking and separated into long fibres (lines) and short fibres (tows). Finally, the fibres are spun into yarn. The moisture content of new fibres is 10-12% and they are hydrophilic. Flax fibres absorb heat and moisture, but because the fibres are not twisted and have a small lumen, heat and moisture are readily dissipated. The fibres are very strong but exhibit little elongation and so are difficult to stretch. Fibre strength and elongation are both highest when the fibres are moist. By applying mechanical pressure, the shape of the fibres can be easily maintained, and creases can be formed in the fabric.

When preserving flax-based historic textiles, storage in acidic environments is avoided. Flax fibres readily dissipate moisture, and therefore dry out easily, resulting in creases and wrinkles forming. Because flax fibres may break in environments with excessively low humidity, maintaining a relative humidity of 50-60% is desirable. In addition, linen is an excellent storage material for long-term preservation and can be used as lining material for tapestries or storage coverings. Pre-treatments for linen are the same as those used for cotton fabrics.

Fig. 5.13 Ramie plant

Fig. 5.14 Ramie fibre 400x (CAMEO

2.3 Ramie, China grass

Ramie or China grass (*Boehmeria nipononivea* L.) consists of stalk bast fibres. Native to Southeast Asia and widely distributed throughout Asia, ramie includes white leaf types with white hairs on the backs of the leaves and green leaf types without hairs. Fibres are obtained by removing the leaves from harvested plants, immersing the stalk in water, removing the skin from the core, and then shaving a thin layer from the skin. Fresh fibres are green to white in colour. The fibres have a broad band-like flat shape, have nodes, often have vertical indentations, and have narrow lumens. Ramie grows to a length of 1-2 m, and fibres have widths of approximately 20-80 μ m. The fibres are easily separated from the woody part, are viscous, and are the next finest cellulose fibres after flax. When impurities are removed, by refining the fibre with an alkali solution, only cellulose remains. Traditionally, fibres were moistened and then bleached by sunlight making them lustrous and white.

Fig. 5.15 Hemp plant (Photo:Crispin Jones)

Fig. 5.16 Hemp fibre 400x (CAMEO)

2.4 Hemp

Hemp (*Cannabis Sativa* L.) is an annual plant widely distributed throughout Central Asia. Hemp also consists of bast fibres taken from the stalks. The fibres are pale brown, white or grey in colour. The plant grows to a lengh of 1-2m. The fibres are cylindrical in shape and have nodes and indentations. The lumen is wide. The fibres have lengths of 5-55 mm and widths of approximately 22 μm. The composition of the fibres is 70-80% cellulose, 10% hemicellulose, 6-7% lignin, 3% pectin, and 1% lipids. Degumming and bleaching impart the fibres with lustre.

Fig. 5.17 Jute plant

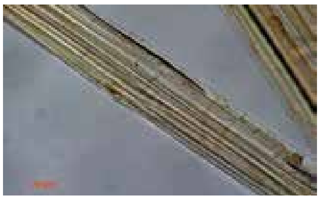


Fig. 5.18 Jute fibre 400x (CAMEO)

2.5 Jute

Jute (*Corchorus capsularis* L.) is an annual herbaceous plant and is widely distributed in tropical and subtropical Asia. Jute is sourced from bast fibres taken from the stalks that are around 1-1.5m long. The fibres are pale brown or white in colour. The fibres have lengths of 1.5-5 mm and widths of 10-30 μm. The fibres have no nodes or striations, and the lumen is elliptical and irregularly sized. The composition of the fibres is 60-65% cellulose, 20-25% lignin, pectin, and lipids. Lignin is readily decomposed by photo-oxidation, which accelerates the oxidation of cellulose. Among bast fibres, jute, which contains large quantities of lignin, readily degrades and exhibits poor durability.

Fibre degradation can be seen in jute-based historic textiles, even those from relatively recent times. Jute fabrics are not suitable as materials for long-term conservation. In cases where jute has been used instead of expensive linen as a tapestry lining, it tore after around 30 years. Where a bast fibre fabric is planned to be used as a conservation material, fibre identification is recommended before use.

Fig. 5.19 Abaca (fibre banana)

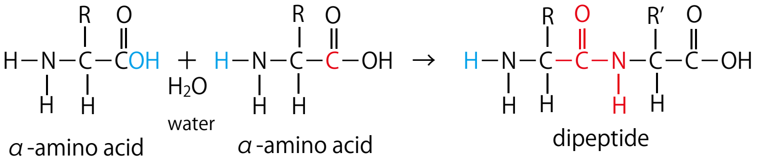
Fig. 5.20 Abaca fibre 400x (CAMEO)

2.6 Manila hemp, (abaca, fibre banana)

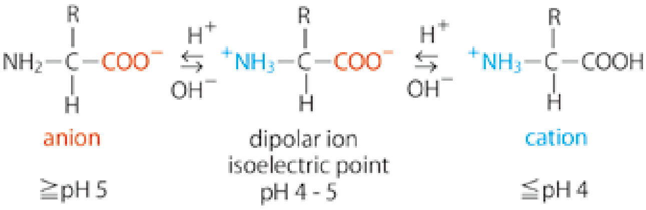
Manila hemp is the leaf fibre of abaca or banana (*Musa textilis* L.). The fibre is obtained from the stalk that is around 1-1.5 m long. The fibres are pale brown in colour and have lengths of 2-12 mm, widths of 16-32 μm. The fibres are circular in shape and have wide, round lumens. The composition of the fibres is 70-80% cellulose, 15% hemicellulose, 6-7% lignin, 0.3% pectin and 0.1% lipids. The fibres are strong and buoyant, exhibit tensile strength and corrosion resistance, and are used as ropes for ships. The pulp is used for paper. Due to its high lignin content, Manila hemp is not suitable as a conservation material.

3. Natural Protein Fibres

The main fibres that contain proteins as primary components are animal hair, such as sheep's wool, and cocoon fibres, such as silk. Proteins are polymers of amino acids (R–CH(NH_2)–COOH)n, which contain amino (–NH_2) groups and carboxyl (–COOH) groups. Amino acids in which these reactive groups are bonded to a carbon atom are α -amino acids, and form peptide linkages (–CONH–)[6].



Proteins are polypeptides obtained by bonding many amino acids. Amino acids are substances that have an isoelectric point, which is an electrically balanced pH where positive and negative charges cancel each other out in an aqueous solution. Amino groups are ionized to NH^{3+} and carboxyl groups are ionized to –COO$^-$ in water, and therefore exhibit both acidic and basic properties.



Proteins act as bases when dissolved in strong acids and act as acids when dissolved in strong bases. The isoelectric points of proteins are in the weakly acidic region(pH 4-5) thus, protein fibres are most stable around this point.

The main fibre proteins are keratin from hair (hair, feather, nails) and sericin (outer layer) and fibroin (inner filament) from silk. Polypeptides of proteins form secondary and tertiary structures that construct three-dimensional structures. For example, hair keratin has an α-helixl structure and silk fibroin has a secondary structure of β-pleated sheet structure. This causes keratin and fibroin to become fibrous structures[7]. Protein changes its nature when reacted with heat, acid and alkali, organic solvents, and heavy metal ions. When the structural arrangement of protein is affected, it will not reverse in most cases.

Textiles containing hair or silk are electrically stable if stored in weakly acidic environments when the fibres are new. Silk kimonos have been stored in paulownia wood chests in Japan wrapped in Japanese Kozo (paper mulberry) paper. In the case of historic textiles, however, proteins decompose and generate acids over time, causing fibre degradation. If the acid concentration increases, further fibre oxidation occurs. Using a storage method in which acids are neutralized using pH-neutral paper is often used to wrap historic protein fibres.

Fig. 5.21 Merino sheep (Photo:Tanner Youk)

Fig. 5.22 Wool fibre 400x (CAMEO)

3.1 Animal hair

Animal hair is deformed skin tissue. Hair is taken from sheep, goats, camels, alpacas, and rabbits. The main component keratin contains disulphide (S-S) bonds derived from cysteine and peptide chains in which large numbers of amino acids are bonded linearly, and these sulphur components cause a characteristic rotten egg smell when hair is burnt. The isoelectric point of keratin is around pH 4.5.

Hair consists of three layers of cell tissue, with the medulla in the centre, inner fibres around the periphery of the medulla, and scale on the outside. Some hair has wave-like twists, known as crimping.

By applying moisture to clumps of hair and rubbing, or by pricking with a jagged needle, the fibres become entangled and felt can be formed. Fine, short, strongly crimped hair with large quantities of scale is easily felted. Care must be taken that textiles consisting of hair fibres are not left close to artefacts (for example, bronze items) that react with sulphur in museum storage and display cases.

3.2 Sheep's wool[8]

Sheep's wool is made of fibres shorn from sheep (*Ovis aries*). It varies in terms of colour, length, and thickness according to the sheep’s breed, the part of the sheep shorn, and the time of the year that shearing occurred. In general, fine wool is short, and thick wool is long. Wool that has a length of approximately 10 cm or longer is used in products for which durable worsted yarn is required. Wool with a length of less than 10 cm is used in products such as spun yarn for warmth and softness. The moisture content of sheep's wool is 10-15% and it is hydrophilic. When wool absorbs water, it swells and increases plasticity, which further increases with temperature rise. Wool starts to decompose at 125-130°C, has an ignition temperature of 349℃ , and is a natural flame-retardant. The maximum ironing temperature of wool is 150°C. If wool is exposed to light for long periods, the scale breaks down and the strength of the wool deteriorates. Keratin exhibits good resistance to acids but is readily swollen by, and dissolved in, alkalis. Soaps and alkaline degumming agents damage wool. Neutral metal salts have little effect on wool. However, when treated with salts that are dissociated by acids, for example, alum which includes aluminium, the salt is absorbed by the wool and can be used as a dyeing mordant.

In addition, wool felt, and fabrics containing sulphur, readily corrode metal artefacts, and attract insects, and are, therefore, not suitable for long-term storage or display material in museums.

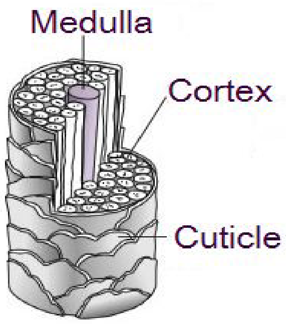


Fig. 5.23 Structure of wool fibre

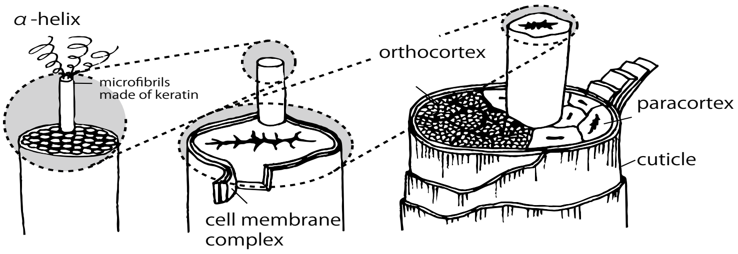


Fig. 5.24 Structure of wool

3.3 Silk[9]

Silk is a cocoon fibre obtained from silkworm cocoons and is broadly classified into cultivated silk (*Bombyx mori*) and wild silk. In silk discharged from the mouths of silkworms, two strands of fibroin are agglutinated by sericin to form a single yarn. The thickness is approximately 2.3-3.6 denier. When sericin is degummed in a warm alkali bath, the lustrous fibroin remains.

The cross-section of the fibroin is trapezoidal or triangular. The length of silk yarns varies according to the type and species but can be 600-2000 m and is a natural filament fibre. The required thickness is achieved by winding several filaments together.

Silk contains a large quantity of air due to its porous nature, has a moisture content of 10-30% and is hydrophilic. When silk absorbs water, it swells and increases its plasticity, which further increases with temperature rise. Silk starts to decompose at 160-170°C. The maximum ironing temperature of silk is 130°C. The isoelectric point of both sericin and fibroin is approximately pH 3.8[10], and these are resistant to weak acids, but undergo hydrolysis at high temperatures. Sericin dissolves in weak alkalis, whereas fibroin does not dissolve, but loses its lustre. Silk dissolves in strong alkalis. Because silk bonds strongly to metal salts, alum, and iron, these have been used as dye mordants and tin as a weighting agent. Common salt acts strongly on silk, and silk exposed to the salts contained in sweat undergoes significant fibre degradation. Silk exhibits low resistance to light and becomes yellow when exposed to sunlight.

Silk fabrics are acidic, easily soiled due to their porous nature, highly hydrophilic, and attractive to insects. For these reasons, silk is not often suitable as storage materials for museum artefacts.

Precautions when using silk for conservation materials include, measuring the degree of acidity before use, as there have been products found to have alkalis remaining after degumming. When using silk fabrics and yarns as conservation materials, they must be pre-washed and pre-shrunk.

Fig. 5.25 Silk worm and cocoon

Fig. 5.26 Silk 400x (CAMEO

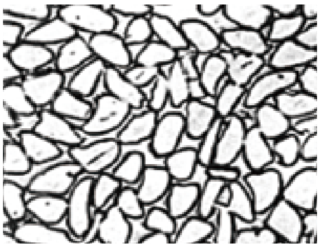


Fig. 5.27 Cross-sectional structure of scoured silk without sericin, the triangular shape of fibroin can be seen independently. (AATCC)

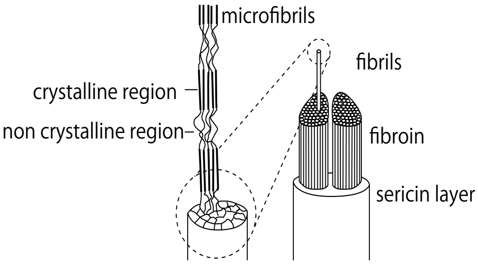


Fig. 5.28 Structure of silk

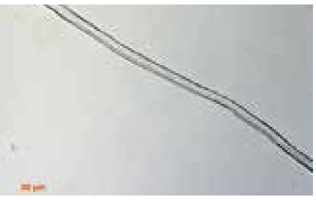


Fig. 5.30 Rayon fibre 200x (CAMEO)

4. Regenerated Fibres

4.1 Rayon

Rayon, derived from cellulose is made from pulp that is dissolved in sodium hydroxide, thereby obtaining alkali cellulose, which is then reacted with carbon disulphide to produce sodium cellulose xanthate. By dissolving this product in a weak sodium hydroxide solution, highly viscous viscose is obtained. This polymer solution is extruded into a sulfuric acid-containing coagulating bath through a spinning nozzle and cellulose filaments are obtained[11].

$$\text{Cellulose} + \underset{\text{sodium hydroxide}}{\text{NaOH}} \rightarrow \underset{\text{alkaline-cellulose}}{\text{Cell} - \text{ONa}} + \underset{\text{water}}{\text{H}_2\text{O}}$$

$$\underset{\text{xanthate}}{\text{Cell}\text{—}\text{OCS}_2\text{Na}} + \underset{\text{suluric acid}}{1/2\,\text{H}_2\text{SO}_4} \rightarrow \underset{\text{cellulose}}{\text{Cell}\text{—}\text{OH}} + \underset{\text{sodium sulfate}}{1/2\,\text{Na}_2\text{SO4}}$$

In 1855, Frenchman Hilaire de Chardonnet (1839-1924) produced pyroxylin by dissolving cellulose nitrate in a volatile solvent and registered this as "Rayon". This was the first chemical fibre. However, cellulose nitrate is highly flammable, and there were cases of dresses catching fire. Cellulose nitrate was widely used as an early synthetic material in accessories such as buttons, brooches, and sequins. When the material degrades, it releases acids. It is safe to isolate the material and store it at a low temperature. In 1898, a method for producing rayon using the viscose method was invented, and in 1905, British company Courtauld succeeded in producing it industrially.

4.2 Cupro

Cupro is made from cellulose-containing pulp which is dissolved in a cuprammonium oxide solution. The obtained highly viscous liquid is fluidized, extruded into a coagulating bath via a spinning nozzle, and then spun. The fibre is lustrous, finer and has a higher degree of polymerization than rayon. In 1918, German company Bemberg succeeded in producing Cupro, which is also known as "Bemberg".

$$\underset{\text{cellulose}}{2\text{Cell} - \text{OH}} + \underset{\text{cuprammonium solution}}{[\text{Cu}(\text{NH}_3)_4](\text{OH})_2} \rightarrow \underset{\text{cellulose cuprammonium complex salt}}{(\text{Cell} - \text{O})_2[\text{Cu}(\text{NH}_3)_4]} + 2\text{H}_2\text{O}$$

$$\underset{\text{cellulose cuprammonium complex salt}}{(\text{Cell} - \text{O})_2[\text{Cu}(\text{NH}_3)_4]} + 3\text{H}_2\text{SO}_4 \rightarrow \underset{\text{regenerated cellulose (Cupra cellulose)}}{2\text{Cell} - \text{OH}} + \text{CuSO}_4 + 2(\text{NH}_4)_2\text{SO}_4$$

Fig. 5.31 Acetate fibre 400x (CAMEO)

4.3 Acetate (diacetate, triacetate)[13]

Cellulose triacetate is obtained by converting hydroxyl groups in the cellulose into acetate groups using acetic acid anhydride. When the obtained highly viscous liquid is passed through a spinning nozzle and dried using hot air, smooth lustrous fibres are obtained. In 1924, the company British Celanese succeeded in industrializing this process.

$$\underset{\text{cellulose}}{\text{Cell—(OH)}_3} + \underset{\text{acetic anhydride}}{3(\text{CH}_3\text{CO})_2\text{O}} \rightarrow \underset{\text{cellulose triacetate}}{\text{Cell—(OCOCH}_3)_3} + 3\text{CH}_3\text{COOH}$$

$$\underset{\text{cellulose triacetate}}{\text{Cell—(OCOCH}_3)_3} + \text{H}_2\text{O} \rightarrow \underset{\text{secondary cellulose acetate}}{\text{Cell} - (\text{OCOCH}_3)_2\text{OH}} + \text{CH}_3\text{COOH}$$

The regenerated fibres rayon, cupra and acetate contain cellulose as a primary component, and can therefore be dyed with direct dyes, reactive dyes, and sulphide dyes. Although some materials such as non-woven rayon, are widely used in conservation treatments, these should only be used temporarily. Regenerated cellulose fibres are not suitable as long-term storage materials for conservation.

In museums with collections of modern materials, there have been reports of early regenerated polymers readily degrading. In collections containing flammable cellulose nitrate films, maintaining low-temperature storage is necessary to prevent acidic build-up and combustion. In costume collections, as cellulose-based fibres degrade, volatile acids released react with other substances in the storerooms, producing acidic environments, particularly in the presence of chloride and sulphate ions. The presence of these acids leads to a chain of material degradation[6]. Countermeasures, in addition to identifying the distinct sour odour released, include; using a reagent to detect the source, placing the artefact(s) in storage with an alkaline buffering material, and isolating the items in a separate room. Another method proposed is sealing the article in an oxygen-free packaging system and storing it in a low-temperature storage room (a large refrigerator) at 0-10 °C. A growth in the use of low-temperature storage is expected in museums containing collections of modern materials (e.g. The Costume Institute, The Metropolitan Museum of Art, New York has constructed low-temperature storage areas.)[14] The ever-increasing degradation of synthetic fibres, and the contamination of surrounding environments, is a serious escalating problem in the conservation of modern materials.

5. Synthetic fibres

Synthetic fibres are produced from coal, petroleum, or natural gas, as raw materials, and by subjecting organic compounds to polymerization reactions; creating new covalent bonds between low molecular weight compounds and producing polymer compounds.

5.1 Nylon[15]

Nylon is a polyamide-based synthetic fibre, and in which monomers are condensed and bonded together by many amino acids forming peptide bonds (–CONH–). Nylon was synthesized in 1935 by Wallace Carothers (1896-1937) of the American company DuPont. To synthesize nylon 66, adipic acid and hexamethylenediamine are mixed at equimolar concentrations in water.

Fig. 5.32 Nylon fibre (DuPont) 400x(CAMEO)

$$\mathrm{n\ H_2N(CH_2)_6NH_2 + n\ HOOC(CH_2)_4COOH \rightarrow -\!\!\left[HN(CH_2)_6NHOC(CH_2)_4CO\right]\!\!-_n}$$

hexamethylenediamine adipic acid nylon 66

The polymer is washed with water, and spinning is carried out, either by direct spinning or by cutting the polymer into chips, melting, and then spinning. The fibres are smooth and light and have a high extension recovery rate. The fibres melt at 250°C, have a maximum ironing temperature of 130°C, and are thermoplastic. The fibres have a moisture content of 4% and are hydrophilic. Nylon is readily decomposed by acids or ultraviolet radiation and is somewhat resistant to alkalis. Nylon fibres are amide-based fibres, and can, therefore, like silk or wool, be dyed with acidic dyes or metalized acidic dyes.

There have been reports of nylon materials stored in museums undergoing degradation such as hardening. In terms of storage, it is recommended to wrap nylon in neutral paper or alkaline paper to neutralize its oxidation.

Nylon-based conservation materials were used as liquid adhesives and consolidation agents in the 1960s. Nylon degrades and hardens over time, and no longer exhibits reversibility in solvents[9]. Nylon net has been widely used as a reinforcing material in textile conservation since the 1960s because it is semi-transparent, easily stretchable and can be dyed in-house with acid dyes. Usage examples include covering chairs with torn surfaces or supporting bias-cut fine silk dresses. Despite its problems, nylon net is still used today as a conservation material because of its usefulness and because of the controlled environment of museums.

Fig. 5.33 Polyester fibre 400x (CAMEO)

Fig. 5.34 Polyester resin

5.2 Polyester[16]

Polyesters are polycondensation products of dicarboxylic acids and polyalcohol, and are polymers formed by ester bonds (–COO–) between molecules. Basic synthesis involves subjecting a polyalcohol that has many hydroxyl groups (–OH) and a compound with multiple carboxyl groups (–COOH) in a dehydrating condensation process. A typical polyester is (PET) poly(ethylene terephthalate), produced by subjecting terephthalic acid and ethylene glycol in a dehydrating condensation reaction/process.

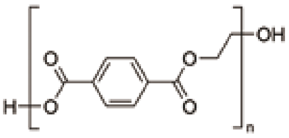


Fig. 5.35 Polyester

terephthalic acid (TPA) + ethylene glycol (EG) → terephthalic acid bis (ethylene glycol) ester
→ poly(ethylene terephthalate) (PET)

Forming fibres involves melting and then spinning the polymer. Polyester fibres have a moisture content of 0.4%, are not electrically charged, and are hydrophobic, absorbing almost no water. Polyester fibres melt at 250°C, have a maximum ironing temperature of 150°C and are thermoplastic. The fibres are resistant to acids and bases at low temperatures and are stable. The fibres are dyed using a disperse dye and by applying pressure.

In textile conservation, polyester support materials are often used when the artefact is degraded due to metal salt components, such as iron mordant or tin weighting because polyester is the least chemically affected among textile fibres. Polyester fibres cannot be dyed unless subjected to high pressures, thus materials need to be chosen from a commercial range or dyed by a dyeing company. As a long-term conservation material, polyester exhibits low hygroscopicity, and is easily soiled due to static electricity and therefore is not suitable for use as covering material. However, because polyester fibres do not retain moisture they are suitable as an inner cushioning material.

Microfibre cloth (lens cleaner) made with polyester and nylon is often used for surface cleaning artefacts in museums. Fine slits shaped into the microfibre which are less than 2 μm, attract and help to remove debris and oily soiling products.

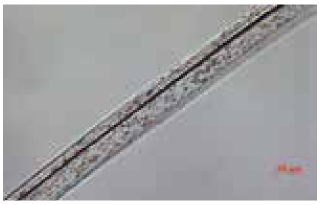
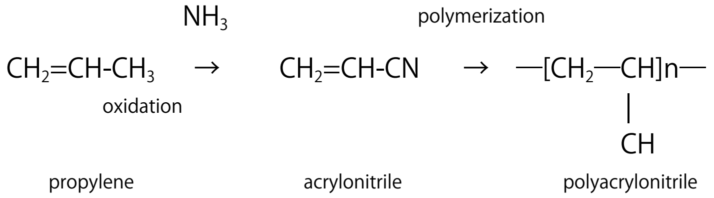


Fig. 5.36 Acrylic fibre 400x (CAMEO)

5.3 Acrylic[17]

Fibres consisting of polymers derived from acrylonitrile are known as acrylic fibres. Acrylic fibres are synthesized by oxidizing propylene to acrylonitrile in the presence of ammonia.



$$CH_2{=}CH{-}CH_3 \xrightarrow[\text{oxidation}]{NH_3} CH_2{=}CH{-}CN \xrightarrow{\text{polymerization}} —[CH_2—\underset{\displaystyle CH}{\underset{|}{CH}}]n—$$

To form fibres, the polymer is melted and then spun. Acrylic fibres are smooth, lustrous, stretchable, and light-resistant. The fibres have a moisture content of 1-2.5%, are negatively charged and are hydrophilic fibres able to absorb small quantities of water. The fibres melt at 230 °C and have a maximum ironing temperature of 130 °C. The fibres are resistant to acids and alkalis at low temperatures and are stable. The fibres can be dyed with cationic dyes.

Acrylic products are chemically stable, transparent, and easily processed, and are therefore widely used in museums as glazing materials for framed pictures and display mounting materials.

Acrylic adhesives have been reported as being stable in accelerated degradation tests as conservation materials. Acrylic fibres are not commonly used to the same extent as polyester fibres as long-term conservation materials in museums.

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15. Op.cit.1, p. 60.
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17. Op.cit.1, p. 61.

Fibre photography references

CAMEO (Conservation & Art Materials Encyclopedia Online)
https://cameo.mfa.org/wiki/Main_Page
AATCC (American Association of Textile Chemists and Colorists). Appendix 1: Photomicrographs of common textile material, Technical Manual, 2001.

6 Identification of Fibres

The aim of identifying the fibre is to understand the content of the fabric. Methods employed for identification are categorized into either physical or chemical tests[1-2]. In conservation, although it requires sampling, physical methods, such as microscopic examination, are favoured over chemical methods such as burn, melt, and stain tests, following the principle of non-destruction of cultural property. Most often the use of a naked flame is forbidden in conservation laboratories.

Instrumental analysis such as SEM, and FTIR (Fourier transform infrared spectroscopy) should be referred to a specialist.

Fig. 6.1 Photograph before removing the sample

1. Collecting samples

Collecting samples directly from a textile for analysis depends on each institution's policy. Always discuss and ask for permission from whoever is responsible for the textile to avoid any misunderstanding. Loose fibres and yarns should not be used for analysis because they could be intrusive from another object, and the results may impede accurate academic study. Do not wrap or place sample yarns on paper or cloth but place them inside aluminium foil or glass containers to avoid contamination with modern fibres.

Fig. 6.2 Photograph after removing the sample

1.1 Tools and equipment

Camera, stereomicroscope, ruler, scale, brown glass tube, label, scalpel, scissors, forceps, polythene bag, surgical gloves without powder, object record sheet.

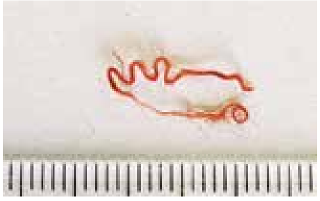


Fig. 6.3 Sample ID WRwt-1 (wool red weft), photograph with a scale.

1.2 Method

1. Photograph the sample area before and after sample removal. Use a scalpel or scissors to carefully cut off the sample, taking care not to pull the sample.
2. Examine the sample under high magnification (stereomicroscope) and remove any debris.
3. Measure the sample and take photographs with a ruler inside the image.
4. Weigh the sample on a scale.
5. Place the sample in a glass tube, label and put it in a polyethylene bag.
6. Store the sample in a cool and dark place.
7. Keep a detailed record.

Fig. 6.4 Storing samples

2. Examination of fibre using microscopes: longitudinal views

Optical examination and feeling tests are the first steps taken to identify a historic fibre. Visual characteristics and the handle or feel can often reveal the content of a fibre. If sampling is permitted, the first/most basic scientific test carried out is to observe the physical properties of a fibre using a light microscope. When sampling, take a photograph before and after removing the sample and record its location and characteristics. A yarn of approximately 10 mm is sufficient as a sample. Under the microscope, the exterior of the fibre is observed, and its characteristics are compared with references. Generally, a longitudinal observation is sufficient, but if necessary, a cross-section is examined. Most often, natural fibres may be identified by this method and after an examination is executed the fibres should be collected

Fig. 6.5 Light microscope

and stored to allow re-testing in the future. When a light microscope is not enough to identify the fibre, chemical tests, such as melt and stain tests, may be required. Pre-testing with known fibres should be performed to familiarize with the testing methods and results. Utmost care should be taken since chemical tests are based on identifying new fibres and ancient fibres may simply disintegrate during the chemical process[3-4].

2.1 Tools and equipment

Light microscope (x10-400), slide glass, cover glass, distilled water, 50 % glycerine in water, mounted needle, sharp knife, scissors, forceps, pipet, blotting paper.

2.2 Method

1. Cut the sample yarn to 5-10 mm.
2. Tease the yarn into fibres using a mounted needle.
3. Place several fibres onto a glass slide.
4. Add a drop of water or 50 % glycerine and cover with a cover glass.
5. Observe the fibre and compare it with known references.

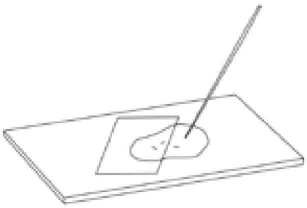
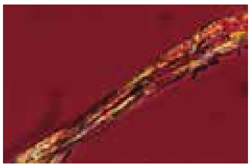
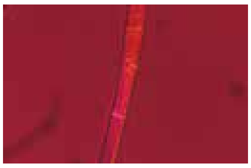
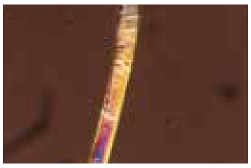
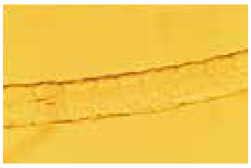
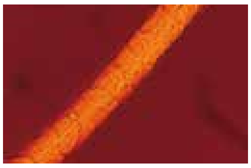
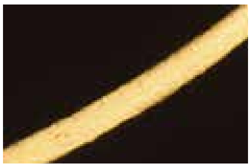
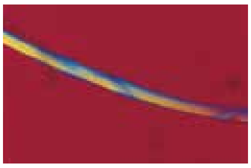
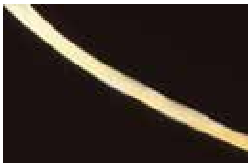


Fig. 6.6 Preparing a glass slide.

* Conservation & Art Materials Encyclopedia Online (CAMEO)
Fibre Reference Library
http://cameo.mfa.org/wiki/Fiber_Reference_Image_Library

Table 6.1 Microscopic images of fibres.

Fibre	White light	Polarizer	Polarizer and condenser
Cotton			
	20 x	200 x	200 x
Flax (linen)			
	200 x	200 x	200 x
Wool			
	200 x	200 x	200 x
Silk			
	200 x	200 x	200 x

Sample preparation and photographs by the author.

3. Fibre solubility test


Fig. 6.7
Silk Linen
Formic acid


Fig. 6.8
Cotton Wool
Formic acid


Fig. 6.9
Cotton Wool
Sodium hydroxide


Fig. 6.10
Rayon Acetate
Sodium hydroxide

It is useful to know the solubility of fibres in acid and alkali solutions. Such information will help us to understand fibre properties, carry out fibre identification and to find aqueous solutions which will not affect materials of historic textiles when considering treatment options. In this test, based on Japan Industrial Standard JIS L 1030-1: 2006 for the identification of fibers[5-6], standard fabrics are used, and the organic solvents used in textile conservation have been added.

3.1 Reference samples and chemicals

Standard test fabrics: International Standard Organization ISO 105 Japan Industrial Standard JIS L 0803 Cotton, linen, silk, wool
Rayon, acetate, nylon, acryl, polyester
Acid and alkali: 35 % hydrochloric acid(HCl), 85% formic acid, glacial acid (100% acetic acid), distilled water or de-ionised water, 20-30 % ammonia, 5 % sodium hydroxide
Organic solvent: methanol*, ethanol, acetone, ethyl acetate, methyl ethyl ketone* N, N dimethyl formamide (DMF)*, white spirit (Industrial methylated spirit)
*Solvents used in dye analysis and their common use are limited.

3.2 Tools

Test tube with 12 mm diameter, test tube holder, pipet, forceps, tray label, blotting paper, pH indicator strip (pH 0-14).

3.3 Method

1. Cut the fabrics into 5 x 5 mm squares.
2. Measure the pH of the reagents (acid and alkali) with pH indicator strips.
3. Add 3-4 drops of reagent into the test tube.
4. Put the fabrics into the test tube.
5. Observe the colour, swelling and solubility of the fabrics.
6. Record the results.

Table 6.2 Solubility of fibres in reagents Notation:○=Soluble ×=Insoluble △=Partly soluble

Solvent	Cotton	Flax	Silk	Wool	Rayon	Acetate	Nylon	Acryl	Polyester
35% hydrochloric acid (HCl) (pH0)	×	×	○	×	○	○	○	×	×
85% formic acid (pH0)	△	△	○	○	×	○	○	×	○
100% acetic acid	×	×	×	×	×	○	×	×	×
Distilled water (pH7)	×	×	×	×	×	×	×	×	×
28% ammonia (pH12)	×	×	×	×	×	×	×	×	×
5% sodium hydroxide (NaOH) (pH14)	△	△	△	△	×	×	×	×	×
Methanol	×	×	×	×	×	×	×	×	×
Ethanol	×	×	×	×	×	×	×	×	×
Acetone	×	×	×	×	×	○	×	×	×
Ethyl acetate	×	×	×	×	×	×	×	×	×
Methyl ethyl ketone	×	×	×	×	×	×	×	×	×
DMF	×	×	×	×	×	○	○ (Nylon 6)	×	×
White spirit	×	×	×	×	×	×	×	×	×

4. Stain Tests

The dyeing or stain test uses a colour indicator to differentiate and identify fibres based on their dyeability with dyes. Fibres don't dye with just any dye, and there are dyes that are compatible with particular fibres.

4.1 Iodine test[7]

Soak the fibres in iodine (potassium iodine solution*) for 30 seconds to 1 minute. Rinse the fibre with water. Observe the stain and its colour. Within natural fibres, cotton will not stain but wool will stain brown and silk light brown. Within synthetic fibres, acetate will stain light brown and nylon dark brown.

*Dissolve 2 g of potassium iodide and 1 g of iodine in 100 ml of water.

Fig. 6.11 Soak the fibres with iodine solution.

Fig. 6.12 Rinse the fibres.

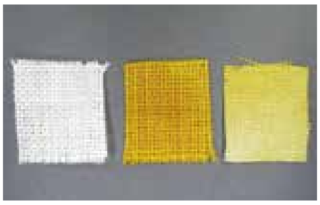


Fig. 6.13 Iodine test
Cotton, wool, silk.

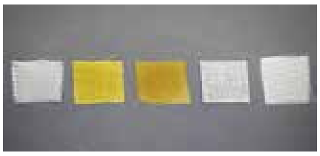


Fig. 6.14 Iodine test
Rayon, acetate, nylon, acryl, polyester

5.2 Shirlastain (ICI)[8]

This stain test is formulated by the principle of the particular affinity of certain dyestuffs with particular fibres and contains a mixture of dyes to identify a range of fibres.

・Shirlastain A

Shirlastain A is a test used for identifying natural fibres and regenerated cellulosic fibres such as rayon and acetate[6]. The sample yarn is first wetted thoroughly. It is then immersed in the test solution at room temperature for 2 minutes, washed, dried, and the colour is noted.

・Shirlastain C

Shirlastain C is a test used for identifying a range of cellulosic fibres. It should be used after Shirlastain A has identified cellulose. The sample yarn is first wetted thoroughly. It is then immersed in the test solution at room temperature for 5 minutes, washed, dried and the colour is noted.

・Shirlastain E

Shirlastain E is a test used for identifying synthetic fibres. The sample yarn is immersed in a boiling test solution for 2 minutes, washed, dried, and the colour is noted.

Table 6.3 Stain colours produced using Shirlastain[9]

Type	Boiled linen	Bleached flax (linen)	Raw cotton	Scoured cotton	Mercerised cotton	Wool	Gummed Silk	Degummed silk
Shirlastain A	Dark purplish-grey	Violet blue	Pale purple	Lilac	Purple	Golden yellow	Very dark brown	Brownish orange
Shirlastain C	-	Light grey-green, flecked pink	Mauve to reddish brown	Off white to greyish-pink	-	-	-	-
Shirlastain E	-		Dull Pink	-	-	Dark Green	Dark Blue	-

4.3 Kayastain Q (Nihon Kayaku, Japan)

Weigh the fibre and measure the same amount of Kayastain Q as the weight of the fibre. Dissolve the powder in a 1:100 ratio of hot water (60-70 ℃). If the amount of fibre is small, make up a 1 % aqueous solution (w/v) (1 g Kayastain Q with 100 ml water). Heat the dye solution and insert the fibre before it reaches boiling point. Boil for 5 minutes, take out the fibre, wash and dry. The stain colour of the various fibres are seen in the sample in (Figure 6.15).

Fig. 6.15 Kayastain Q

4.4 Bokenstain II (Boken, Japan)

Weigh the fibre and measure 5 times the amount of Bokenstain II of the weight of the fibre. Dissolve the powder in a 1:100 ratio of hot water. If the amount of fibre is small, make up a 5% aqueous solution (v/v) (5 ml Bokenstain II with 95 ml water). Heat the dye solution and insert the fibre before it reaches boiling point. Boil for 2 minutes, take out the fibre, wash and dry. The stain colour of the various fibres are seen in the sample in (Figure 6.16).

Fig. 6.16 Bokenstain II

4.5 Fuchsin S (Acid fuchsin)

Make up an 0.8% aqueous solution (w/v)(0.8 g Fuchsin S with 100ml). Insert the fibre in the dye solution and boil for 5 minutes, wash and dry. The stain colour of the various fibres are seen in the sample in (Figure 6.17).

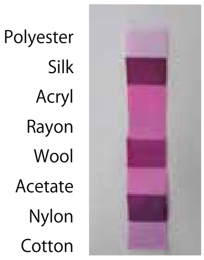


Fig. 6.17 Fuchsin S

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7 Dyes

Dyes can be categorized as either natural dyes or synthetic dyes. Both types of dyes are polyphenols with many phenol groups (hydroxyl groups –OH bonded to aromatic rings C_6H_5)(Figure 7.1).The difference between dyes and pigments, which are both colouring agents, is that dyes dissolve in water and are compatible with fibres and pigments do not dissolve in water and are not compatible with fibres. Dyeing is the process in which a colouring material is bonded to and adsorbed by fibres. Dyeing methods include dip dyeing and printing. Pigments, including organic types, require the use of a binder, such as an adhesive, to fix a pigment onto fibres.

Types of dyes include both natural dyes and synthetic dyes, where the principal structure of the colouring matter is a polyphenol. The first synthetic dye was invented in 1856 by UK scientist William Perkin (1838-1907) when he synthesized aniline from coal tar and chromium acid, obtaining a purple solution he named “mauveine.” Before this, dyeing had always utilized natural dyes. Further aniline dyes, including red, blue, purple, and green, followed soon after. In the 1862 World Exhibition in London, fabrics dyed with bright aniline dyes were exhibited displaying England’s technical advancement within the textile industry[1].

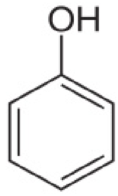

Fig. 7.1 Phenol

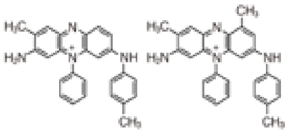

Fig. 7.2 Mauvein A (left) and B (right)
C.I. 50245 (Aniline basic dye)

Fig. 7.3 Mauvein made by Perkin in 1856. Science Museum, London.

The mechanism of dyeing

In water, when the dyestuff hits the surface of the fibre and remains there for a while, it slowly migrates into the inner structure of the fibre from the amorphous regions and eventually bonds with the fibre.

Dyes and fibres both have functional groups with a polarity which attract each other with plus (+) or minus (–) electrical forces or molecule forces and form primary or secondary bonds (van der Waals forces, hydrogen bonds and dipolar bonds) in the dyeing process. The fibre will not be dyed unless coupled with a dye which is electrically attracted by these forces.

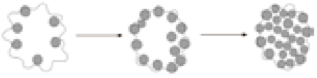

Fig. 7.4 Dyeing mechanism: dyes hitting the fibre surface.

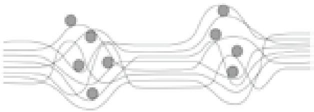

Fig. 7.5 Dyeing mechanism: migration of dyes in the amorphous regions of the fibre.

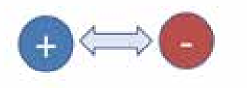

Fig. 7.6 + and - electric force between dye and fibre

Fig. 7.7 Molecule force between dye and fibre.

① Cellulose fibres have some areas with + or – charges.

② Protein fibres have + or – charges.

③ Acryl fibres have – charges.

④ Polyester fibres do not have + or – charges.

In the 1950s reactive dyes were invented, which attach to the fibre using covalent bonds. Before this, all dyes bonded to the fibre with either secondary bonds or salt linkages (e.g., metal mordants)[2]. These new reactive dyes included both hydrophilic colourants which dissolve easily in water and lipophilic colourants which hardly dissolve in water. In this process dye molecules migrate to fibres and, to dye the fibres, complex chemical changes occur; the state of hydration of the dye molecules changes, reactions with auxiliary agents facilitate bonding between molecules and

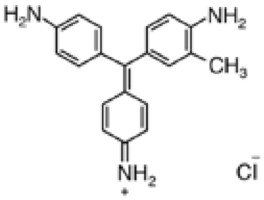

Fig. 7.9 Basic Violet 14 C.I. 42510
(Aniline basic dye)
'Magenta' was synthesised in 1856.

changes occur in the state of the fibres. Because hydrophobic synthetic fibres, such as polyesters, are not easily dyed in water, dyeing methods were developed including applying high pressure to force the dye into the fibres or kneading the dye with the synthetic resin during yarn production. Dyes are selected based on their compatibility with fibres (Table 7.1).

As new synthetic colourants are synthesized, and the structures of the dyes are clarified, the dyes are recorded in the Colour Index International (C.I.) and assigned a C.I. code. For example, the brand name Cibacet Red 2G would be Disperse Red 17, C.I. 11210. This is the international standard code for colouring materials. These codes are recorded in a database of dyes and pigments which is jointly administered by The Society of Dyers and Colourists (SDC) and The American Association of Textile Chemists and Colorists (AATCC) (Table 7.2).

Table 7.1 Affinity of fibres and dyes

Notation：○ = Good affinity, △ = Moderate affinity, × = No affinity

Dye	**Cellulose Cotton, Bast fibres (linen), Rayon**	**Protein Polyamides (hair fibre, silk, nylon)**	**Acetate**	**Acryl**	**Polyester**
Direct Dye	○	×	×	×	×
Acid dye	×	○	×	×	×
Mordant dye	×	○	×	×	×
Metal complex dyes	×	○	×	×	×
Acid mordant dye	×	○	×	×	×
Basic dyes Cationic dye	△	×	×	○	△
Reactive dye	○	△	×	×	×
Vat Dye	○	△	×	×	×
Sulphur dye	○	×	×	×	×
Naphthol dye	○	×	△	×	×
Disperse dye	×	×	○	△	○

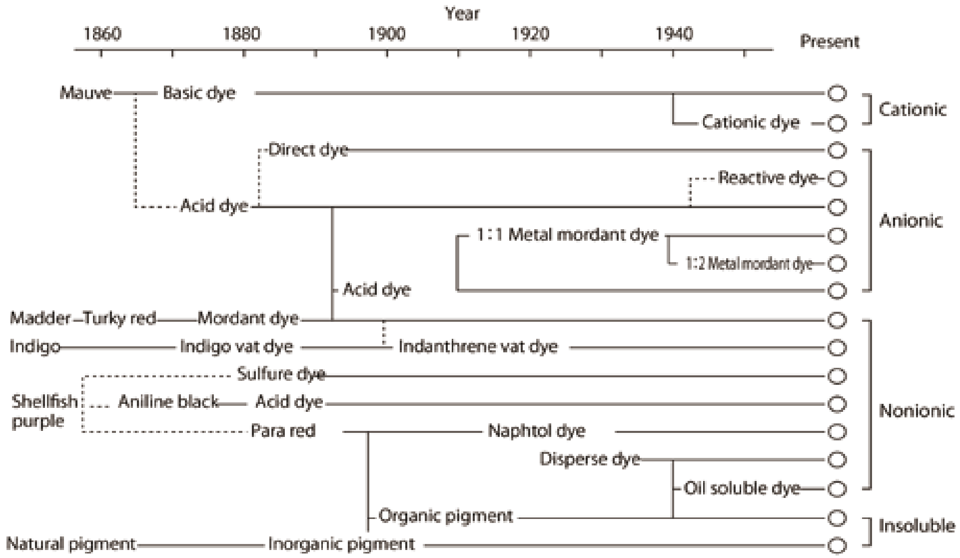

Fig. 7.8 Chronological change from natural dyes to synthetic dyes

Table 7.2 Chronology of the years of invention of the main synthetic dyes[3]

Name of Dye	Date of invention	Inventor	Colour Index No.	Dye class
Mauve	1856	Perkin	C.I. Mauvelpk@oipkl; 50245	Basic
Magenta	1856	Natanson	C.I. Basic Violet 14	Basic
Acid Orange	1858	Hofman	C.I. Acid Orange 93	Acid
Aniline Blue	1861	Gorard, laire	C.I. Solvent Blue 3	Basic
Aniline Black	1863	Lightfoot	C.I. Oxidation Base 1	Oxidation
Bismarck Brown	1863	Martius	C.I. Basic Brown 1	Basic
Alizarin	1868	Gräbe, Liebermann	C.I. Mordant red 11	Mordant
Synthetic indigo	1870 (1890)	Baeyer, Emmerling, Heumann	C.I. Vat Blue 1	Vat
Mordant for cellulose fibres	1870	Dale & Brooke	-	Tannin-antimony mordant
Sulphur Brown	1873	Cachou De Laval	C.I.Basic Blue 9	Sulphide
Chrysoidine	1875	Caro	C.I. Mordant Yellow 1	Basic
Methylene Blue	1876	Caro	C.I. Basic Blue 9	Basic
Alizarin Yellow 2G	1877	Nietski	C.I. Mordant Yellow 1	Chrome after mordant
Naphthol yellow S	1879	Caro	C.I. Acid Yellow 1	Acid
Paranitraniline red and Para red	1880	Holliday	C.I. Azonic Diazo Component 37 and C.I. Azonic Coupling Component 1	Azo
Congo red	1884	Böttiger	C.I. Direct Red 28	Direct
Primuline	1887	Green	C.I. Direct Yellow 59	Diazotising
After treatment of direct dyes	1889	Bayer Co.	-	Direct dye post processing (copper sulphate)
Chrome Violet	1890	Runkel	C.I. Mordant dye 43500	Chromium after mordant
Sulphur Black	1896	Vidal	C.I. Sulphur Black 1	Sulphide
Diamine Brown MR	1908	Casella Color Co.	C.I. Direct Brown 2	Coupling
Indanthren Blue RS	1901	Bohn	C.I. Vat Blue 4	Vat
Naphthol AS	1911	Winther, Laska, Zitscher	C.I Azoic Coupling Component 2	Azo
Neolan Green BL	1918	Grob	C.I. Acid Green 12	1:1 Chrome complex
Indigosol	1924	Bader & Sunder	C.I. Soluble Vat Blue 1	Water soluble vat
Irgalan	1950	Geigy Co.		1:2 Metal Complex
Procions	1955	ICI Co.		Reactive
Cibacron	1957	Ciba Co.		Reactive

1. Colour fastness

Colour fastness is a standard for numerically evaluating the "durability" (difficulty of colour change) of a colour dyed or pigmented. Test methods are stipulated by the International Standards (ISO) and in Japan, the Japanese Industrial Standards (JIS), and in America by the American Association of Textile Chemists and Dyes (AATCC)[4]. Standard tests check for resistance to light, washing and rubbing, confirming "discolouration" of the colour (discolouration and fading) and "staining" which is colour transfer to the surroundings.

The test results are graded from 1 to 8 for fastness to light and from 1 to 5 for fastness to washing. The larger the value the colouring shows resistance (good) and the smaller the value it shows less resistance (poor). Dyed fabrics used for conservation are recommended to have a light fastness level of 5 or higher[5].

Category	High (good)		Low (poor)	
Lightfastness	8	4	1	grade
Washfastness	5	3	1	grade

2. Dye class

2.1 Direct dyes[7] (Anionic)

Direct dyes have a planar molecular structure with extensive conjugated double bonds that spread over the fibre. Direct dyes have anionic moieties (sulfonate groups ($-SO_3H$), nitro groups ($-NO_2$) or azo groups ($-N{=}N-$). Bonds between direct dyes and fibre molecules utilize van der Waals forces and hydrogen bonds. A neutral salt is added during dyeing which dissociates in water producing cations, which facilitate bonding between the fibres and the dye. Direct dyes come in many colours and are relatively resistant to light but some dyes show poor resistance to laundering. Suitable fibres for direct dyes are rayon and cellulose-based cotton and bast fibres. Tannic acid, which is found in natural dyes such as walnuts, and turmeric are direct dyes. Solophenyl® (Huntsman) and Sirius® dyes (Dystar) are all types of direct dyes used in textile conservation.

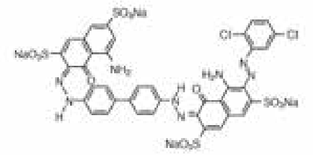

Fig. 7.10 Direct Blue 11 C.I. 30350 (Direct dye)

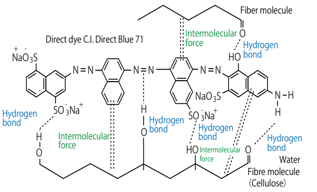

Fig. 7.11 Image of fibre and dye bonds in direct dyes.

Table 7.4 Dye fastness of direct dye, Direct Blue 11 C.I. 30350[8]

Test	Light fastness	Wash fastness		Fastness to sweat	Fastness to oxidation bleach		Fastness to sea water	
		Fading	Staining		Fading	Staining	Fading	Staining
ISO	5	4	2	3	4	-	3	-
AATC	5	1	2	4	4	-	1	-

2.2 Acidic dyes[9] (Anionic)

Acidic dyes have hydroxyl groups ($-OH$) or amino groups ($-NH_2$) in their molecules and, in terms of molecular size, do not necessarily have planar molecular structures. Acidic dyes have anionic moieties (sulfonate groups $-SO_3H$) and may have azo groups ($-N{=}N-$) or anthraquinone-based structures. Bonds between acidic dyes and fibre molecules are ionic bonds between anions in the dye and cations in the fibres, hydrogen bonds, or van der Waals forces. An acid is added during dyeing because the acid generates cations, which facilitate bonding between the fibres and the dye. If the pH exceeds 5.5, compatibility with the fibre decreases. Acidic dyes come in many colours and are relatively resistant to light, but some dyes show poor resistance to laundering. Suitable fibres are protein-based fibres such as wool and silk that are stable in acidic conditions and amide fibres such as nylon.

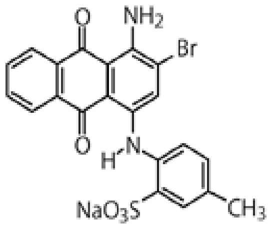

Fig. 7.12 Acid Blue 78 C.I. 62105 (Anthraquinone type acid dye)

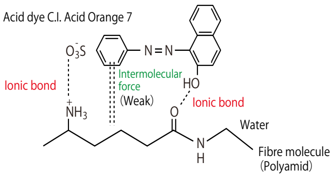

Fig. 7.13 Image of the fibre and dye bonds in acid dyes.

Table 7.5 Dye fastness of acid dye, Acid Blue 78 C.I. 62105[10]

Test	Light fastness	Wash fastness		Fastness to sweat	Fastness to oxidation bleach		Fastness to sea water	
		Fading	Staining		Fading	Staining	Fading	Staining
ISO	5-6	3	3	3-4	2	3-4	3-4	-
AATC	5	3	2	4	2-3	4	4	-

2.3 Mordant Dyes[11]Anionic, nonionic)

Most natural dyes, such as madder, are mordant dyes. Because dye molecules do not directly bond to fibres, dyeing is carried out by dipping fibres in a solution of metal salts (such as aluminium, iron, tin) or an oxide (such as tannin) to fix these to the fibre. This is known as mordanting. The mordanted fibres are then dipped in a dye solution to produce an insoluble complex salt of the metal and the dye. Even with the same dye, different metal salts produce different colours, resulting in mordant dyes also known as polygenetic dyes. Mordant dyes with a colour fastness grade over 4 are limited to colourants such as madder and cochineal which have an anthraquinone structure. Suitable fibres for mordant dyes are silk and wool and depending on the pre-treatment of fibres, cotton may be dyed as well.

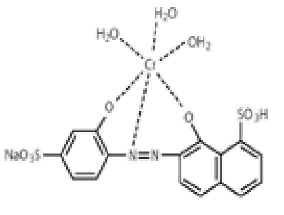

Fig. 7.14 Acid Blue159 (1:1 metal complex dye)

2.4 Metal complex dyes[12](Anionic)

Metal complex salt dyes are acidic dyes containing azo groups (–N=N–), hydroxyl groups (–OH) and carboxyl groups (–COOH) within the molecule and form complex salts with metals such as cobalt and chromium. Depending on the coupling ratio between the metal and the dye, metal complex dyes can be one-to-one types, with one metal atom per one dye molecule, or one-to-two types, with one metal atom per two dye molecules. Dyes come in many colours and one-to-two types are more colour fast than one-to-one types, but lack in colour brightness. The one-to-two types can be dyed in a neutral dye process. The bonds between the dye and fibre molecules are ionic and hydrogen bonds and van der Waals forces. Metal complex dyes are highly resistant to light and laundering. Suitable fibres include protein-based fibres, such as wool and silk that are stable in acidic conditions and amide fibres, such as nylon. Irgalan* and Lanaset* dyes (Huntsman) used in textile conservation are typical examples of metal complex dyes.

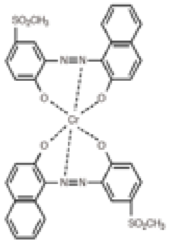

Fig. 7.15 Acid Violet 78 C.I. 12205 (1:2 metal complex dye)

Table 7.6 Dye fastness of metal complex dye Acid Violet 87 C.I. 15675[13]

Test	Light fastness	Wash fastness		Fastness to sweat	Fastness to oxidation bleach		Fastness to sea water	
		Fading	Staining		Fading	Staining	Fading	Staining
ISO	6-7	4-5	5	5	4-5	3	5	5

2.5 Acidic mordant dyes (chrome dyes)[14](Anionic)

Acidic mordant dyes exhibit the properties of both acidic dyes and mordant dyes. Sodium sulfonate groups in the dye molecules are mordanted by a chromium salt, producing an insoluble complex salt. These are also known as chromium dyes. Acidic mordant dyes are highly resistant to light and laundering. Suitable fibres include nylon (amide) and proteinaceous hair and silk.

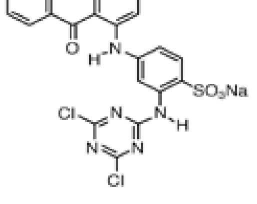

Fig. 7.16 Reactive Blue 4 C.I. 61205 (Reactive dye)

2.6. Reactive dyes[15](Anionic)

Reactive dyes have reactive groups, such as dichlorotriazinyl, within the molecular structure. These form ether bonds (–O–) with hydroxyl groups (–OH) when dyeing cellulosic fibres in aqueous alkaline solutions. Reactive dyes produce covalent bonds and are therefore durable. Reactive dyes are resistant to light and laundering but are susceptible to friction. Suitable fibres are cellulosic fibres, such as cotton, bast fibre and rayon.

React in an aqueous alkaline solution

$$N_3C_3Cl_2(NHdye) + HO\text{-}cellulose \rightarrow N_3C_3Cl\,(NHdye)(Ocellulose) + HCl$$

dichlorotriazinyl dye cellulose fibre bond of dye and fibre

There is a direct correlation between the functional groups and the reaction temperature of the dye molecules. These reactions are divided into three main categories: highly reactive low-temperature types (40~50C, dichlorotriazinyl group), medium-reactive mesothermal types (60C, vinyl sulfone group or vinyl amide group), and low reactive high-temperature types (70~90C, monochlorotriazinyl group and trichloro pyrimidine group). Reactive dyes for wool contain a sulfonic acid group. Reactive dyes are light, and have a high degree of washing fastness, but are vulnerable to abrasion. Suitable fibres are cellulosic fibres, including cotton, linen and rayon, and amide-based fibres, such as hair (wool), silk and nylon. In the conservation and restoration fields of Europe and the United States, medium-reactive mesothermal Levafix® dye and Remasol® dye (DyStar) are used for paper dyeing. There are several dyeing methods, but the two-bath method is the simplest, in which the dye is absorbed into the fibres in a neutral dye bath and then fixed in an alkaline bath as the temperature is raised. The Lanaset ® (Huntsman®) dye is mixed with a metal complex salt-acid dye in a ratio of 1: 2 with the reactive dye for wool. Due to this combination, it can be dyed in a neutral aqueous solution. Since it contains two types of dyes mixed, it can easily produce an uneven dyeing result.

Table 7.7 Dye fastness of reactive dye, Reactive Blue 4 C.I. 61205[16]

Test	Light fastness	Wash fastness		Fastness to sweat	Fastness to oxidation bleach		Fastness to sea water	
		Fading	Staining		Fading	Staining	Fading	Staining
ISO	6	3-4	4-5	4	4	5	4-5	4-5

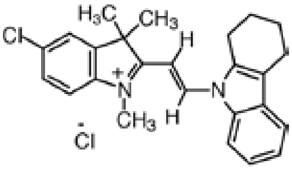

Fig. 7.17 Basic Yellow 23 C.I. 48100 (Basic dye)

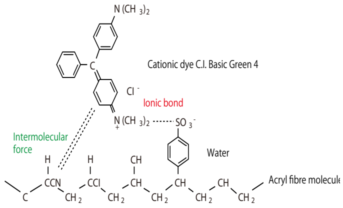

Fig. 7.18 Image of the fibre and dye bonds in basic dyes.

2.7 Basic dyes (cationic dyes)[17]

Basic dyes have quaternary amino structures($–NH_2$, $–NHCH_3$, $–NHCH_2CH_3$) or carbonyl groups ($–C(=O)–$) within the molecule structure, and are relatively small in terms of molecular size. Bonds between basic dyes and fibre molecules include ionic bonds between cations in the dye and anions in the fibres, van der Waals bonds, or hydrogen bonds. Basic Dyes are not effective on cellulose fibres but these fibres can be dyed after being treated with an acidic substance such as tannic acid. Among natural dyes, *Phellodendron amurense* (berberine) is a basic dye. Early aniline-based dyes were basic dyes and have poor colourfastness. Care should be taken when exhibiting and conserving items containing these dyes. Basic dyes suitable for synthetic fibres, such as acryl, polyester, and polypropylene were developed, and are differentiated, by calling them 'cationic dyes'. Colour fastness to both light and laundering is good in cationic dyed synthetics.

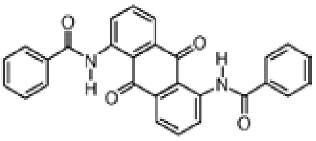

Fig. 7.19 Vat Yellow 3 C.I. 61725 (Vat dye)

2.8 Vat dyes[18]

Vat dyes are broadly classified into indigo dyes and anthraquinone dyes. Vat dyes have carbonyl groups （–C(=O)–）, are hydrophobic, and do not dissolve in water. When dyeing with vat dyes, carbonyl groups in dye molecules are reduced by a reducing agent (hydrosulphite) in an aqueous alkaline solution, enabling the dye to dissolve in water. The fibres are then impregnated with the dye. To fix the dye, the fibres are oxidized in the air. Indigo and indanthrene dyes are typical examples of vat dyes. Suitable fibres for vat dyes are cellulosic fibres, including cotton, bast fibre and rayon. Vat dyes are highly resistant to light and laundering but are susceptible to friction. Among natural dyes, indigo and shellfish purple (indigo bromine) are vat dyes.

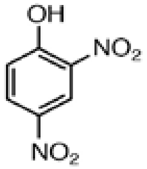

Fig. 7.20 Sulphur Black 1 C.I. 53185 (Sulphur dye)

2.9 Sulphur Dyes[19]

Sulphur dyes are dyed by reducing the dyes with sodium sulphide in an alkaline aqueous solution, permeating the dyes into the fibres, and oxidizing them in the air. The bonds between the dye and fibre molecules are hydrogen bonds and van der Waals forces. Suitable fibres for sulphur dyes are cotton fibres. Sulphur dyes are highly resistant to light and laundering but are susceptible to friction. It has often been used to dye cellulosic fibers in black, brown and navy blue. Currently, its use is decreasing due to environmental problems caused by sulphur and damages to the fibre. As time passes, sulphur contained in the sulphur dyes is oxidized producing sulphuric acid, causing corrosion of the fibres and surrounding objects. In museum collections, modern cellulosic textiles in dark colours that have degraded and have an acidic smell may be suspected to be dyed with sulphur dyes. These items should be isolated from other objects. Do not use sulphur-dyed textiles for conservation or display in museums.

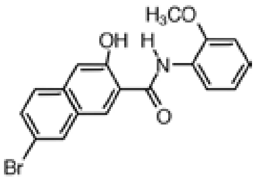

Fig. 7.21 Azoic coupling component 45 C.I. 37566 (Naphthol AS B1, azo type naphthol dye)

2.10 Naphthol dyes[20]

Naphthol dyes are also known as Azoic dyes or azo dyes in which two organic groups are bonded with an azo (–N=N–) group. Dyeing with naphthol dyes is carried out by treating fibres with naphthol (a grounder), and then chemically reacting with a diazo compound (a developer), to form a colourant that is insoluble in water. Naphthol dyes produce vivid colours and exhibit good dye fastness. Suitable fibres for naphthol dyes are cellulosic fibres, including cotton, bast fibres, rayon, and acetate. Naphthol dyes are highly resistant to light and laundering but are susceptible to friction and readily dissolve in organic solvents.

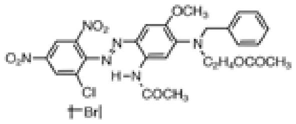

Fig. 7.22 Disperse Blue 130 C.I. 64500 (Azo type disperse dye).

2.11 Disperse dyes[21]

Disperse dyes have azo groups (–N=N–) or hydroxyl groups (–OH) and are relatively small in terms of molecular size. Disperse dyes do not have ionic moieties and have hydrophilic groups within the molecule. Disperse dyes are not water soluble and need to be dissolved using dispersions. Dyes penetrate gaps between fibres and bond to the fibres using van der Waals bonds or hydrogen bonds. Therefore, it is necessary to dye at high temperatures (130-135 ℃ , pH 4.5-5). In the industry, pressured dyeing equipment is used to allow the dye to penetrate and disperse into the fibres. Suitable fibres for disperse dyes are polyester, acetate, and acrylic. Disperse dyes are highly resistant to light and laundering. When dyed without pressure, the resultant colours are pale. When dyeing polyester fabric or net for textile conservation, it is normally sent to a specialist dye firm.

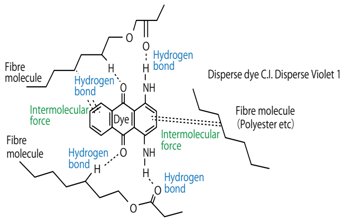

Fig. 7.23 Image of the fibre and dye bonds in disperse dyes.

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16. Op.cit., 7, p. 290-291.
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19. Op.cit., 7, p. 291.
20. Op.cit., 7, p. 286.
21. Op.cit., 7, p. 289.

8

Dyeing Reference Samples of Natural Dyes

The first step in dye analysis is to prepare dyed reference samples with yarns and fabrics for comparison. The selection of dyes mentioned in this chapter is based on information shared by Ms. Maro Harutuynyan, textile conservator and Dr. Lilia Avenasian, ethnographer of the National History Museum of Armenia, Professor Zelpure Talayan of the Armenian National Academy of Science, and archaeologist Lucine Margaryan. (Table 8.1, 8.2.)

The dyeing procedure provided is sourced from literature by the German organic chemist Helmut Schweppe[1] who conducted courses on the identification of historic dyes in the late 1980s.

In textile conservation today, fabrics and yarns to be used for conserving objects are not dyed with natural dyes. Natural dyed support fabrics and fibres make future scientific identification of original dyes confusing; colour matching is difficult, and they do not satisfy the same durability criteria as current synthetic dyes.

1. Dyes and colours

Colouring matters of natural dyes are extracted from plants and insects. Each colouring matter has a particular organic molecule structure made up of polyphenols which selectively absorb light. Humans capture light with their eyes, which is reflected and transmitted to the brain, which perceives these transmissions as colour. Without light (energy), the colouring matter does not absorb or reflect light, and humans cannot see colour.

For an organic compound to have colour, it needs a chromophore that absorbs a particular wavelength. The energy of the visual spectrum is better absorbed by chromophores containing carbon $=$ carbon ($> C = C <$), carbon $=$ oxygen ($> C = O$) in the molecule compounds. When colouring matter absorbs energy, the electron in the molecule moves from the ground state to the excited state, and this transition is repeated between the stages for as long as energy is supplied. Organic colouring matter with conjugated double bonds (conjugated π electrons) is apt to electron transfer by energy absorbance. For an organic colouring matter to function as a dye that bonds to fibres, the molecule must be large and flat or have functional groups such as a hydroxyl group ($-OH$), an amino group ($-NH_2$), or a carboxyl group ($-COOH$) which bond to metal ions (mordants) and form insoluble metal complexes.[2]

2. Classification of natural dyes

Natural dyes are classified into three categories according to the methods of dyeing. Here are some examples which include Armenian (Table 8, 8.2) and Japanese dyes.

Direct dye	Brown: Walnut husk, gall, *Yamamomo* (bark of *Myrica rubra*)
	Yellow: Turmeric, Saffron, *Kuchinashi* (fruit of *Gardenia jasminoides*)
	Red: Safflower (carthamin)
	Purple: Orchil (lichen)
Mordant dye*	Red: Plant dyes: Dyer's madder, brazilwood Insect dyes: Armenian cochineal, cochineal, kermes, lac
	Yellow: Weld, Young fustic, Quercitron, Persian berry, Safflower (safflower yellow), *Kariyasu* (*Miscanthus tinctorius*), *Enjyu* (*Sophora japonica)*, Cephararia (yellow scabiosa), Immortelle (everlasting)
	Purple: Alkanet (*Alkanna tinctoria*), *Shikon* (*Lithospermumerythrorhizon*)
Vat dye	Blue: Woad (*Isatis tinctoria*), Indian indigo (*Indigofera tinctoria*), Japanese indigo (*Persicaria tinctoria*) and plants containing indigo.
	Purple: Shellfish purple containing 6,6’-dibromo-indigo

*The type of mordant will change the colour of dyed fibre. The colours in this list are based on the use of alum as a mordant.

Fig. 8.1 Dyer's madder
Rubia tinctorum L.
Toron (Armenian), Marena (Latin)
Given from Dr. Lilia Avanesyan, Ethnographer, History Museum of Armenia. 4.12. 2012

2.1 Direct dye

Direct dyes have an affinity to fibres and the colouring matters often have large, long, and flat molecule structures. The colouring matter and fibre are linked with hydrogen bonds and van der Waals forces (they have a neutral atom that is not electrically charged and contain cohesive forces between molecules) when soaked into the dye solution. Energy in the form of heat is often applied during dyeing to excite the bonding between molecules.

2.2 Mordant dye

Mordant dyes do not have an affinity to natural fibres but because their molecule structures have functional groups such as a hydroxyl group (–OH), an amino group ($-NH_2$) or a carboxyl group (–COOH), colouring matters can bond with metal ions by coordinate linkage. Water-soluble metals such as aluminium (Al^{3+}), iron (Fe^{2+}), tin (Sn^{4+}), copper (Cu^{2+}) and chromium (Cr^{3+}) will turn into metal hydroxides or oxides and bond with fibres and with colouring matters to form insoluble complex salts. Metal ions which are intermediate dyes and fibres are called mordants. Fixing mordants can be carried out before, during and after soaking the fibre in the dye bath. Multi-colours are produced from a single dye by changing the type of mordant used. For this reason, a mordant dye is also called a polychrome dye. For example, alizarin, the main colouring matter of madder, will dye red with alum and purple with iron.

Fig. 8.2 Armenian cochineal
Porphyrophora hameli Brandt.
Armenian cochineal
Vordan karmir (Armenian)
Given from Dr. Lilia Avanesyan, Ethnographer, History Museum of Armenia. 4.12. 2012

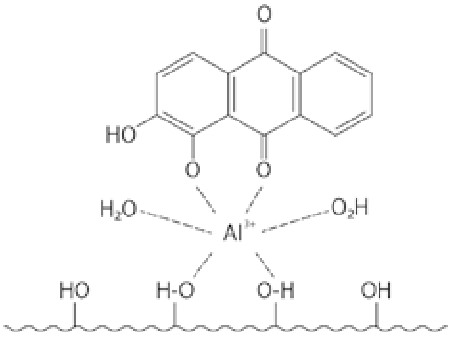
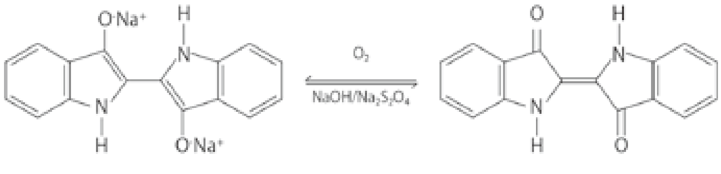


Fig. 8.3 The aluminium complex of alizarin on cotton

2.3 Vat dye

The colourants of vat dyes are insoluble in water. To fix the colouring matter to the fibres, the carbonyl group (–C(=O)–) of the molecules are reduced in an alkaline solution which makes it water-soluble. In the past, vat dyes were reduced using urine (alkali), sugar and fruit (reducing agent). Today chemicals such as sodium carbonate (Na_2CO_3) and sodium hydroxide (NaOH) are used as alkali agents and hydrosulphite ($Na_2S_2O_4$) as a reducing agent. Indigo will turn green in a soluble state forming leuco-indigo and will turn blue with oxidation in the air.



leuco-indigo (soluble)

indigo (insoluble)

Fig. 8.4 Structure of indigo (left: reduced state, right: oxidised state.

Table 8.1 Armenian natural dyes

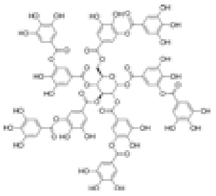
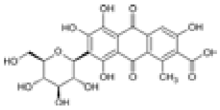
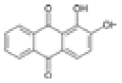
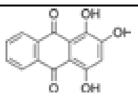
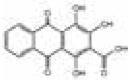
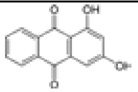
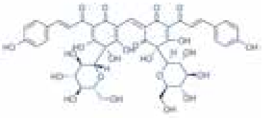
Dye name	Scientific name	Origin	Main colouring matter	Classification	Colour
Walnut Husks 	*Juglans regia*	Husk	 Tannic acid	Direct Dye	Brown
Armenian cochineal[3-5] 	*Porphyrophora hamelii* Brandt.	Insect	 Carminic acid $C_{22}H_{20}O_{13}$ Kermesic acid $C_{16}H_{10}O_8$ Flavokermesic acid $C_{16}H_{11}O_0$	Mordant Dye	Red (Alum)
Madder 	*Rubia tinctorum* L.	Root	 Alizarin $C_{14}H_8O_4$  Purpurin $C_{14}H_8O_5$  Pseudopurpurin $C_{15}H_8O_7$  Xanthopurpurin $C_{14}H_8O_4$	Mordant Dye	Red (Alum) Purple (Iron) Brown (Iron)
Safflower 	*Carthamus tinctorius* L.	Petals	Safflower yellow (safflomin A) (safflomin B)	Mordant Dyes	Yellow (Alum)
			 Carthamin $C_{43}H_{42}O_{22}$	Direct dye	Red
Immortelle (evelastings) 	*Helichrysum arenarium* L.	Flower	Flavonoids	Mordant dye	Yellow (Alum)

Table 8.2 Armenian natural dyes

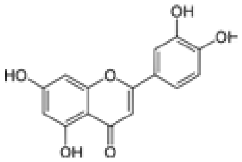
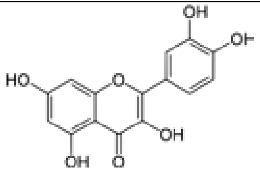
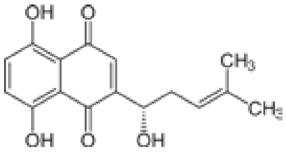
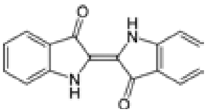
Dye name	Scientific name	Origin	Main colouring matter	Classification	Colour
Cephalaria **(yellow scabious)** [6-7] 	*Cephalaria procera* Fisch. & Avé-Lall.	Flower	 Luteolin $C_{15}H_{10}O_6$  Quercetin $C_{15}H_{10}O_7$	Mordant Dyes	Yellow（Alum)
Alkanet[3-5] 	*Alkanna tinctoria* L.	Root	 Alkannin $C_{16}H_{16}O_5$	Mordant Dyes Soak well with boiling water, Soak overnight in alcohol to extract the pigment.	Purple (Alum)
Woad 	*Isatis tinctoria* L.	Leaf	 Indigotin $C_{16}H_{10}N_2O_2$	Vat Dye	Blue
Indian indigo 	*Indigofera tinctoria* L.	Leaf	Indigotin	Vat Dye	Blue

Table 8.3 Comparison of components in red insect dyes.[3-5.]

Name	Coccus type	Origin	Colouring component				
			carminic acid	flavokermesic acid	kermesic acid	dcII*	laccaic acid
Armenian cochineal	*Porphyrophora hamelii* Brandt	Armenia, Azerbaijan, Arrarat valley	○	○	○	○	—
Polish cochineal	*Porphyrophora polonica* Linnaeus	Middle and Eastern Europe, Germany, Poland, Ukraine	○	○	○	○	—
Kermes	*Kermes vermilio* Planchon	Southern Europe, Near East, Turkey	—	○	○	—	—
Lac	*Kerria lacca*	India, South East Asia	—	○	○	—	A, B
Cochineal	*Dactylopius coccus* Costa	Mexico, South America	○	○	○	○	—

*Unknown component

3. Dyeing terminology

Extraction of colouring matter (decoction)

Extraction of colouring matter in plants and insects with water or hot water.

Wetting out of the fibre

Pre-soaking the fibre before dying to prevent colouring irregularity.

Dye bath

Extraction of colouring matter with added water for dyeing

o.w.f. (Of weight of fibre)

The proportion of the weight of materials to the weight of fibre.

Liquor Ratio L.R.

The proportion of the total amount of water for a dye bath to that of the fibre.
(Fibre : Water/ 1:100)

The proportion depends on the volume of fibre and the shape of the container for dyeing.

Mordant

Mordant is a water-soluble metal such as alum, iron and tin which intermediately bonds the fibre and the colouring matter. Colour development depends on the type of mordant used.

Potassium hydrogen tartrate (cream of tartar, tartaric acid)

Potassium hydrogen tartrate ($KC_4H_5O_6$), originally formed from wine, is used as a pH regulator.

4. Fabric and yarn

Fig. 8.5 Fabric for sample dying
Cotton, Silk, Wool (JIS L 0803)

For making reference fabrics, it is recommended to use white test fabrics made for colourfastness test for dyes. For example, International Organization for Standardization ISO 105 and Japan Industrial Standard JIS L 0803 are standard fabrics. When using shop-bought cotton fabrics, test for starch, and if present, remove it before dying.

5. Tools

Scale, scissors, hot plate, stainless steel pot/vat/ bowl, beaker, sieve, pH indicator strips (pH 0-14), glass or stainless-steel rods, heat protective gloves, latex gloves, and towel.

6. Preparation of yarn

Wind the yarn in small skeins and tie with polyester thread in between the yarns (Figure 8.6-8.9).

7. Dyeing yarns

When dyeing yarn hanks, use a stainless-steel pot or bowl. So as not to tangle the threads, insert a stainless-steel or glass rod through the hanks (Figure 8.9). Rest the rod over the container and let the yarn drop into the dye bath. To ensure even dyeing regularly rotate the yarn over the rod to change the area inserted in the dye. When dyeing a small amount of yarn, use a vat or a beaker. Do not stir the yarn.

8. Dyeing a large piece of fabric

When dyeing a large piece of fabric, use a rectangular stainless-steel vessel. Hold the large fabric on both sides and move forwards and backwards, without inserting air, to achieve an even dye coverage.

Preparation of skein for yarn dyeing

Fig. 8.6 Wind the yarn into a loop

Fig. 8.7 Make a skein

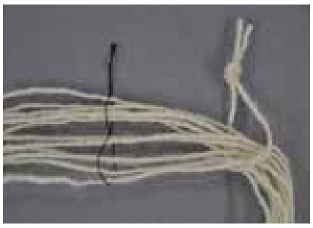


Fig.8.8 Tie inbetween the threads with polyester thread in intervals.

Fig. 8.9 Passing a rod between the loop during dyeing prevents the yarns from tangling.

9. Mordanting methods


Fig. 8.10 Natural alum from an Armenian market.


Fig. 8.11 Potassium aluminium sulphate


Fig. 8.12 Dissolve mordant and soak the fibre.

A mordant is a water-soluble metal salt that bonds to the colouring matter and the fibre. Among the metal salts, a light element, such as alum (potassium aluminium sulphate $KAl(SO_4)_2 \cdot 12H_2OO$)tends to produce light shades while a heavy element, such as ferrous acetate, produces dark shades. There are three types of mordanting procedures.

① Pre-mordanting — mordant the fibre before dyeing.
② One bath dyeing — add the mordant into the dye decoction.
③ After-mordanting — mordant the fibre after dyeing.

9.11 Pre-mordanting

≪ **Alum mordant** ≫
Mordant:Alum 15-25 % o.w.f.
Auxiliary agent: Potassium hydrogen tartrate 25% of the weight of alum.
Not necessary if unavailable.
L.R.: 1:200

≪ **Iron mordant** ≫
Mordant: Iron (iron-II-sulphate) 3 % o.w.f.
Auxiliary agent: Potassium hydrogen tartrate (cream of tartar) 6 % o.w.f.
L.R.: 1:200

≪ **Tin mordant** ≫
Mordant: Tin (tin-II-chloride) 3 % o.w.f.
Auxiliary agent: Potassium hydrogen tartrate 3 % o.w.f.
A small amount of oxalic acid.
L.R.: 1:200

Procedure

1. Calculate and measure the amount of mordant, auxiliary agent and water.
2. Wet out the fibre in water.
3. Place the mordant, auxiliary agent and water into a stainless-steel or glass vessel.
4. Heat and dissolve the mordant. Insert the fibre at 40℃ and stir for 20 minutes at 70℃ .
5. Lower the temperature to 40℃ . Rinse well.
6. When/ If drying immediately, wring lightly. If not, dry in the shade.

9.2 One-bath dyeing/ Simultaneous mordant method

In one-bath dyeing, the dye extract and the mordant are placed into the vessel together and dyed. In Europe, insect dyes such as cochineal and lac were dyed with this method using alum and tin mordants.

9.3 After mordant

An after-mordant process is undertaken after dyeing to alter the colour. Standards for the mordant are as follows. The liquor ratio is 1:20, and the amount of water is adjusted according to the amount of fibre.

Tin (tin-II-chloride) 0.5 % o.w.f.
Iron (iron-II-sulphate) 1 % o.w.f.
Copper (copper sulphate) 1 % o.w.f.

1. Dissolve the mordant in warm water. Put the pre-mordanted and dyed fabric in hot water and mordant it for 20 minutes.
2. Lower the temperature to 40°C and rinse with water.
3. Absorb moisture from the cloth with a towel and dry it indoors.

Practice 1 Dyeing with direct dyes: Walnut husk


Fig. 8.13 Walnut husk


Fig. 8.14 Boil the walnut husk.


Fig. 8.15 Remove the husk and dye the fibre.


Fig. 8.16 Cotton, silk, wool
(no mordant)

Direct dyes can be fixed to fibres by simply extracting the colouring matter from dyes, and soaking fibres in the dye solution. The colouring matter is generally extracted by decoction.

Tannins are a component in a plant which has a bitter or puckery taste. This flavour acts as a protective agent against predation. The colouring matter can easily bond with protein and metal ions. For example, gall ink is produced by bonding ferrous acetate with tannins.

1. Materials

Test fabric: Cotton, wool, silk, 10 × 10 cm, 2 pieces each.
Dye: Walnut husk 100 % o.w.f.
L.R.: 1 : 100-300

2. Dyeing procedure

≪ Material preparation ≫

1. Cut and weigh the fabrics.
2. Calculate and measure the amount of dye and water according to the weight of fibre.
3. Wet out the fibre in water (for at least 1 hour)

≪ Extraction of colouring matter ≫

4. Place the dye and half the amount of water in a stainless-steel vessel and heat for 20 minutes.
5. Sieve the dye and repeat extraction with the remaining water. Add water if needed. The water will evapourate during the extraction process and may need to be topped up.

≪ Dyeing ≫

6. Place the fibre in the dye bath. Raise the temperature to 70-80℃ and stir for 20 minutes. The temperature should be adjusted depending on the fibre type; silk should not exceed 70℃ , and the maximum temperature for cotton and wool is around 90℃ .
7. Lower the temperature to 40℃ . Rinse with water.
8. Wring out the water from the fibre with a towel and dry it in the shade.

≪ After mordant ≫ (Refer to 9.3 After mordant.)

To change the shade of colour, take one piece of each dyed fabric and treat it with an iron mordant.

Fig. 8.17 Petals of saflower

Fig. 8.18 Wash out the safflower yelow

Fig. 8.19 Extract carthamin with alkali

Fig. 8.20 Sieve the dye

Fig. 8.21 Add acid

Fig. 8.22 Dye the fabric and wash well

Fig. 8.23 After dyeing.

Practice 2 Dyeing with direct dyes: Safflower (red)

Dyeing with safflower (dyeing red with carthamin)
Safflower petals contain both yellow (safflower yellow) and red (carthamin) colourants. To dye the fibre red requires the following process: Safflower yellow is first washed out, next carthamin is extracted in an alkaline solution, and then the dye is fixed to the fibre in an acidic solution.

1.Materials

Test fabric: Cotton, wool, silk, 10× 10 cm 1 piece each,
1 large piece of silk fabric (scarf)
Dye: Safflower (petals) 200 % o.w.f.
Auxiliary agents: Sodium carbonate (soda, Na_2CO_3) 50 % o.w.f.
Water 300 % o.w.f.
10 % acetic acid solution

Fig. 8.24 Materials and equipment

2. Dyeing procedure

≪ Preparation of materials ≫

1. Cut the cotton, wool and silk fabric and weigh them with the large piece of silk fabric.
2. Calculate and measure the amount of dye, chemicals, and water according to o.w.f.
3. Wet out the fibre in water.

≪ Extraction of colouring matter ≫

4. Soak the safflower in water overnight.
5. Wash out the yellow colouring matter (safflower yellow). The safflower may be placed in a bag and kneaded.
6. Place the safflower in a container. Add water and sodium carbonate. Check the pH with pH indicator strips and adjust to pH 9-10 (alkaline). Knead the safflower and extract the red colouring matter. The petals will turn yellow-brown.
7. Sieve the extraction. Add extra water if the volume is not enough to generously cover the fabric during the dyeing process.

≪ Dyeing ≫

8. Checking with pH indicator strips, add acetic acid and adjust the pH to 7.5 (weak alkaline).
9. Stir the fibre for 20 minutes. During dyeing, add acetic acid and adjust the pH to 6 (weakly acidic). To dye a large piece of fabric evenly, hold it on both sides and move it backwards and forwards without creating air bubbles.
10. Rinse well with water, wring the water out and dry in the shade.

*To dye a darker red colour, repeat the dyeing, rinsing and drying process.

Practice 3 Dyeing with mordant dyes (heating method): Dyer's madder

In this practice, madder is dyed without a mordant, mordanted with alum, and with ferrous acetate (iron mordant). The colour is also changed using acid and alkali agents. (This practice can also be used for Brazilwood and logwood).

1. Materials

Test fabric: Cotton, wool, silk 10 x 10 cm 6 pieces of each.
(1 without mordant, 4 alum mordanted (alum acid, alkali, iron mordant),
1 iron mordant)
Dye: Dyer's madder 100 % o.w.f.
Mordant: Alum 15-25% o.w.f..
25 % potassium hydrogen tartrate of the weight of mordant,
Iron-II-sulphate 1% o.w.f
Potassium hydrogen tartrate 6 % o.w.f.
pH regulator: Acetic acid, ammonia
L.R.: 1 : 200-300

2.1 Procedure

≪ Material preparation ≫

1. Cut and weigh the fabrics.
2. Calculate and measure the amount of dye, mordant, auxiliary agent, and water according to the weight of fibre.
3. Wet out the fibre in water (for at least 1 hour)

≪ Alum (Al) mordant ≫ (Refer to 9.1 Pre-mordant).

4. Pre-mordant 4 pieces of each cotton, wool, and silk fabric with alum mordant.

≪ Iron(Fe) mordant ≫ (Refer to 9.1 Pre-mordant).

5. Pre-mordant 1 piece of each cotton, wool, and silk fabric with iron mordant.
6. Wet out the fabric samples for at least an hour before dyeing, keeping the different mordants separate.

≪ Extraction of colouring matter ≫

7. Place the dye material (madder root) and half the amount of water in a stainless-steel vessel. Boil for 20 minutes.
8. Sieve the dye and extract solution. Extract the dye for a second time with the other half of the water. Add extra water if the dye solution volume is not enough to cover the fabric during dyeing.

≪ Dyeing ≫

9. Divide the dye extract into three beakers. The volume of dye in each depends on the number of pieces of fabric to be dyed in each beaker. In the first beaker place the untreated fabric samples, In the second beaker place the alum mordant samples, and in the third beaker the iron mordant samples. Add extra water if


Fig. 8.25 Dyer's madder bought in a market in Armenia.


Fig. 8.26 Boil the madder.


Fig. 8.27 Sieve the madder extract.


Fig. 8.28 Dye the pre-mordanted fabric.


Fig. 8.29 From left to right, cotton, silk, wool(pH6.4), wool(pH8)

needed. The fabric should be able to move freely in the liquid. Place the beakers into a flat stainless-steel vessel containing water (a double boiler set up) and heat for 20 minutes. Stir the fabrics occasionally. The brown colouring matter bonds to the fibres at a high temperature. To obtain a clear red colour, the temperature should be maintained at around 65℃ .

10. Lower the temperature to 40℃ and rinse with water.
11. Soak one set (cotton, wool and silk) of alum mordant fabric samples in an acetic acid solution (pH 6.5) and one set in the ammonia solution (pH 8) to adjust the colour.
12. Wring out the water from the fibre with a towel and dry the samples in the shade.

Practice4 Dyeing with mordant dyes (without heat): Dyer's Madder


Fig. 8.30 Crush the madder roots.


Fig. 8.31 Soak the madder in water for extraction.


Fig. 8.32 After 1, 3, 5 hours and 1 and 3 days. Fibres were soaked in the dye solution after mordanting and removed accordingly.

Dyeing without heat has been suggested as an ancient dye method because heating requires fuel, which would have been expensive or hard to source at different times throughout history, and in some locations. With madder, brown colouring matter is apt to bonding with fibres at high temperatures. Dyeing without heat results in clear shades of red when fibres are pre-mordanted (alum). The depth of shade of the colour depends on the concentration of the dye solution and the duration of soaking. In this practice, small hanks of wool yarn are soaked in the dye solution and taken out in intervals to obtain light and dark shades of red. For materials, refer to Practice 3.

≪ Pre-mordanting ≫

1. Soak the yarn in an alum mordant solution overnight to up to 1 week. Stir occasionally.

≪ Extraction of colouring matter ≫

2. Break up the dye material (madder root) into small pieces (the same quantity as W.O.F as used in Practice 3). Soak overnight to up to 1 week, stirring occasionally and sieve the dye. Alternatively, the dye may be powdered and placed in a bag. Knead the bag occasionally.
3. When using several kinds of mordant, divide the dye solution.

≪ Dyeing ≫

4. Soak the yarns in the extracted solution.
5. Take out the yarn in intervals. For example, after 1 hour, 3 hours, 5 hours, 1 day, 3 days, and 5 days.
6. Rinse well and wring out the water from the fibre with a towel. Dry in the shade.


Fig. 8.33 Cephalaria


Fig. 8.34 Boil the cephalaria flowers


Fig. 8.35 Sieve the dye extract.


Fig. 8.36 Dye the pre-mordant fabrics.

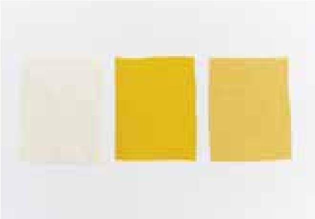


Fig. 8.37 Cotton, silk , wool (Alum)

Practice 5

Dyeing with mordant dyes (yellow plants): Cephalaria or Immortelle flowers

Cephalaria (yellow scabious) and Immortelle (everlasting) contain flavonoids and is used as herbal teas as well as dyes in Armenia.

1. Materials

Test fabrics: Cotton, wool, silk, 10 × 10 cm 2 pieces of each
A large piece of fabric (wool or silk), hanks of yarn (wool)
Dye: Cephalaria or Immortelle flowers 200 % o.w.f.
Mordant: Alum 15-25 % o.w.f.
25 % potassium hydrogen tartrate of the weight of mordant
L. R.: 1 : 200-300
(Adjust the amount of water depending on the volume of fibre and the container).

2. Procedure

≪ Material preparation ≫

1. Calculate and measure the amount of dye, mordant, auxiliary agent, and water according to the weight of fibre.
2. Wet out the fibre in water.

≪ Alum (Al) mordant ≫ (Refer to 9.1 Pre-mordant.)

3. Pre-mordant the fibre with alum.

≪ Extraction of colouring matter ≫

4. Put in the dye and half the amount of water in a stainless-steel vessel and boil for 20 minutes.
5. Sieve dye and solution. Extract the dye for a second time with the other half of the water. Add water if there is not enough dye solution to cover the fibre for even dyeing.

≪ Dyeing ≫

6. Insert the fibre into the dye bath. Raise the temperature, maintaining it at around 50℃ to 70℃ for 20 minutes. Stir continuously.
7. Lower the temperature to 40℃ . Rinse with water.
8. Wring out the water from the fibre with a towel and dry it in the shade.

*When a dark colour is required, repeat dyeing and mordanting.


Fig. 8.38 Immortelle (everlastings)flower


Fig. 8.39 After alum mordant.
Top: wool yarn, bottom: cotton, silk, wool

Practice 6 Dyeing with mordant dyes: Red insect dyes


Fig. 8.40 Cochineal (South American)


Fig. 8.41 Boil the cochineal.


Fig. 8.42 Sieve the dye extract.


Fig. 8.43 Dye the pre-mordant fabric.

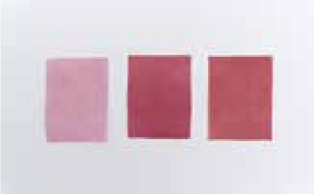


Fig. 8.44 Cotton, silk, wool (alum mordant)


Fig. 8.45 Cotton, silk, wool (alum + tin mordant)


Fig. 8.46 Cotton, silk, wool (iron mordant)

Kermes (kermesic acid), lac (laccaic acid), Armenian cochineal (carminic acid) and cochineal (carminic acid) are all insect red dyes. In this practice, South American cochineal is used because the colouring matter is similar to Armenian cochineal, and it is easier to obtain. Alum, iron and alum and tin mordants are used in this practice. With the alum and tin mordant samples, the fabric will be first mordanted with alum, dyed, and then after-mordanted with tin.

1. Materials

Test fabric: Cotton, wool, silk, 10 × 10 cm, 6 pieces each
(1 no mordant, 1 alum, 1 alum+tin, tin 1, iron 1)
Dye: Cochineal 30 % o.w.f.
Mordant: A. Alum 15-25 % o.w.f. (pre-mordant)
Potassium hydrogen tartrate
(25% of the weight of alum (pre-mordant)
B. Tin 0.5 % o.w.f. (after mordant)
C. Iron 3% o.w.f. (pre-mordant)
L.R.: 1:30~100

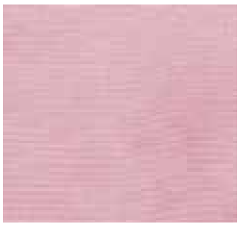


Fig. 8.47 Armenia cochineal (alum mordant), dyed with a single insect given by Dr. Lilia Avahesyan.

2. Procedure

≪ Material preparation ≫

1. Cut the fabrics.
2. Calculate and measure the amount of dye, mordant and auxiliary agent.
3. Wet out the fibre in water.

≪ A. Mordant Alum (Al) and Iron (Fe) ≫ (Refer to 9.1 Pre-mordant.)

4. Pre-mordant two pieces of each of the fabric types with alum (cotton, wool and silk). Pre-mordant one piece of each fabric with iron.

≪ Extraction of colouring matter ≫

5. Place the dye material (cochineal) and half the amount of water in a stainless-steel vessel and boil for 20 minutes.
6. Sieve the dye and solution. Extract the dye for a second time with the other half of the water. Add water if there is not enough dye solution to cover the fibres in order to achive even dyeing.

≪ Dyeing ≫

7. Separate the dye into two containers. Insert the alum mordant fibre in one dye bath, and the iron mordant fabric in the other. Gradually raise the temperature and maintain it at around 50℃ to 70℃ for 20 minutes.
8. Lower the temperature to 40℃ and rinse with water.

≪ B. Mordanting with tin (Sn) ≫ (Refer to 9.3 After mordant)

9. Pre-mordant one fabric sample of each cotton, wool, and silk with tin (for the tin mordant sample). Keep the tin mordant solution.

10. Heat the tin mordant solution and insert the dyed fabric pre-mordanted with alum. Dye for 20 minutes.
11. Lower the temperature to 40℃ and rinse with water.
12. Wring out the water from the fibre with a towel and dry it in the shade.

Practice 7 Dyeing with vat dyes: Indigo


Fig. 8.48 Indian indigo

Indigo is a non-water-soluble dye and is reduced and made soluble in an alkaline solution. In this state, it is absorbed by the fibre and is fixed as indigo when oxidised in the air.


Fig. 8.49 Add water and make a paste.


Fig. 8.50 Reduce indigo in an alkali solution with hydrosulphite.

1. Materials

Test fabric: Cotton, wool, silk 10 × 10 cm each
A large piece of cotton or linen fabric.
Dye: Powdered or solid natural indigo 15 % o.w.f.
(Woad, Indian indigo, Japanese indigo, and others)
Auxiliary agent: Sodium carbonate (soda, Na_2CO_3) 30 % o.w.f
Reducing agent hydrosulphite ($Na_2S_2O_4$) 30 % o.w.f.
L.R.: 1 : 200-300 (Adjust the amount of water depending on the volume of fibre).

2. Procedure

≪ Material preparation ≫

1. Cut the fabric.
2. Weigh the fibre.
3. Measure the amount of dye, chemicals, and water.
4. Wet out the fibre in water.

≪ Solubilizing and reducing indigo ≫

5. Add a small amount of hot water to the indigo to form a paste.
6. In a separate beaker, dissolve sodium carbonate with a small amount of water.
7. In a large container place the indigo paste, and sodium carbonate solution, and add water, stirring gently (pH 10).
8. Add hydrosulphite (reducing agent) and stir gently.

Fig. 8.51 Colourless soluble indigo is aborbed by the fibre.

Fig. 8.52 The indigo turns blue with oxidation.

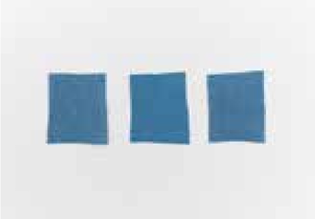


Fig. 8.53 Cotton, silk wool (indigo)

9.Heat the dye to 55℃ and leave it to cool for 20 minutes.When the solution turns green, the reduction is complete. The iridescent spots forming on the surface of the liquid are called Indigo flowers and are a sign the indigo is ready. If the solution returns to blue, it is a sign that leuco-indigo has oxidised. Add further hydrosulphite to reduce it once more.

≪ Dyeing ≫

11.Soak the fibre in the dye bath. For dark colours, leave for around 15-20 minutes.

12.Take out the fibre and expose it to the air.

When to colour changes from green to blue, the reduction is complete. To dye dark shades, repeat the dyeing and airing process.

13.Rinse well, wring out water from the fibre with a towel and dry in the shade.

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1. Helmut Schweppe.1986. *Practical Hints on Dyeing with Natural Dyes: Production of Comparative Dyeings for the Identification of Dyes on Historic Textile Materials. Sponsored by the Conservation Analytical Laboratory of the Smithsonian Institution, 15th through 19th September 1986*. Washington D.C.: Smithsonian Institution.
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9 Dye Analysis 1
Colour & Solubility test

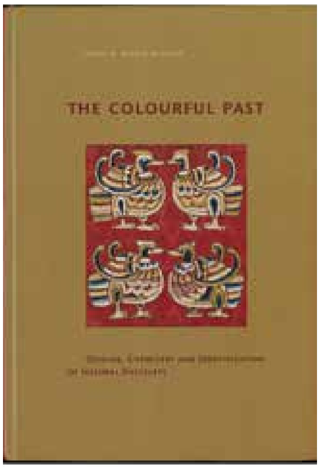

Fig. 9.1 The Colourful Past 2004

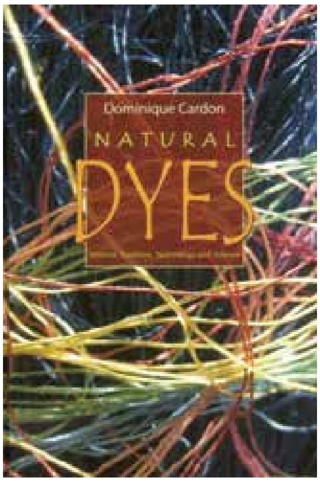

Fig. 9.2 Natural Dyes 2010

Visual observation of the colour of a textile is the first step in identifying dyes. Practising dyeing with natural dyes will help the conservator to understand dye processes and colour. It is also important for a conservator to understand the chemical characteristics of dyes through identification tests. For example, madder will bleed and turn orange in strong acid, remain unchanged in water and turn red-purple in strong alkali solutions. Knowledge of how dyes will react in various pH and organic solvents is useful when deciding treatments and storage materials.

There are several methods to identify dyes, from simple chemical spot tests to specialized instrumental analysis. Reference samples of dyestuffs and dyed fibres are essential when conducting the identification of dyes. Chemical spot tests and thin-layer chromatography (TLC) are simple and relatively low-cost tests. More accurate instrumental analysis should be conducted by a specialist. The main methods are described below.

1. Analysis of the colouring matter with reagents

Reagents are used to determine dissolution and colour change of the dye and compared to a reference to determine the dye.

① Solubility tests

② Colour tests

2. Analysis of the colouring matter with chromatography

Chromatography (chroma meaning colour and graphy meaning to write) is a technique for the separation of a mixture by passing it in solution or gas through a medium in which the components move at different rates, hence making it possible to identify what it is.

2.1 Thin-layer chromatography (TLC)[1]

This is a non-instrumental technique using an absorbent material such as a silica plate (a stationary phase) and solvents (a mobile phase). An extracted dye sample is applied on the plate and material separation is achieved by the capillary action of the solvent. The unknown matter is tested against a known matter (reference sample) for comparison. It is a simple, cost-effective, and relatively accurate technique often used by conservators.

2.2 High-performance liquid chromatography with photo-diode array detection (HPLC- PDA)[2]

HPLC is an instrumental analysis method in which the mobile phase solvent is mechanically flowed at high pressure, and the analyte is passed through the stationary phase column (separation material), and the retention time (retention time) is determined using the difference in affinity between the compound and the separation material with time. Furthermore, the compound is exposed to light with a light-emitting diode array (Photo diode array-PDA) and the absorbance is measured. These data are qualitatively compared with standard substances. This is the most widely used qualitative method for dye analysis in historic textiles.

2.3 Liquid chromatography with mass spectrometry (LC-MS)

LC-MS is an instrumental analysis method that measures the mass of molecules when separating and detecting compounds by the HPLC method. Structural analysis is possible even without standard samples.

3. Analysis of coloured surfaces with spectrophotometry

Fig. 9.3 Spectrophotometer (Konica Minolta)

Spectrophotometry is the quantitative measurement of the reflection or absorption properties of a material as a function of wavelength.

3.1 Spectrometer

Fig. 9.4 Measuring the surface colour of the threads.

Colourimetric determination of dyed fabrics is usually carried out using a colourimeter that irradiates light with wavelengths in the ultraviolet and visible regions (360-780 nm) and measures the reflected light. It is useful for quantitatively grasping and recording the colour change of textiles before and after cleaning treatment and before and after exhibition. The spectral reflectance spectrum and the C.I.E L*a*b* system are often used in cultural property preservation areas.

3.2 Three dimensional fluorescence analysis

Dye molecules have conjugated double bonds and aromatics, and since these have absorption in the near-ultraviolet region, when they absorb ultraviolet rays, their electronic state changes and they excite fluorescence. Identification of the components is limited for dyed fabrics containing multiple components or when the colour is faded. Used as a non-destructive analytical method.

Fig. 9.5 CIE 1979 Lab Colour Space[3] (Konica Minolta)

4. Interpretation of results

The same colouring matter may be contained in various dyestuffs, and it is not always possible to identify the dye solely from analytical results. Information on regional, archaeological, and historic plant distribution and trade, and ethnographic and historic dye practices in the region or time relevant to the textile, are vital when interpreting scientific results as to what a dyestuff may be[3].

5. Solubility test to identify dyes

Solubility (extraction) and colour change of dyes in particular chemical reagents can help distinguish a dye and understand its chemical characteristics. A sample yarn of approximately 1 cm is placed in a glass tube with several drops of reagent. Extraction of the colouring matter and colour change of the fibre is observed[4-5].

It is important to choose an organic solvent which does not affect the dye when carrying out solvent cleaning, spot cleaning or adhesive support treatments. On the other hand, it is necessary to extract colouring matter from the fibre in dye analysis. Knowing the solubility of dyes in organic solvents is important for a conservator.

When using organic solvents, always practice under the fume hood and ventilate the room by opening the windows. Where there are no facilities, do not use these solvents.

5.1 Test samples

Sample: Fabrics dyed with natural dye.

Solvent: Distilled water, ethanol, 100% acetic acid, 20-30% ammonia

5.2 Tools

Test tube with a 12 mm diameter, test tube holder, silicon stopper for a test tube, pipet, forceps, tray, label, blotting paper, pH indicator strip (pH 0-14).

5.3 Method

1. Cut the fabrics into 5 x 5 mm square. Use 1cm of yarn when sampling from a textile.
2. Add 3-4 drops of reagent into the test tube.
3. Insert the fabrics into the test tubes.
4. Observe the colour, extraction of colouring matter and its colour. Record the results.
5. Samples from the textile should be washed, dried, and collected.

5.4 Result

The reference of the solubility and colour test is shown in Table 9.1 Actual examples are shown in Figures. 9.6 to 9.13.

The madder dyed fabrics did not change with neutral distilled water and ethanol. With acetic acid, it turned yellow and the dye dissolved. Ammonia changed the colour to reddish purple, and the pigment was dissolved.

The colour of the indigo-dyed fabric did not change, but it dissolved slightly in acetic acid.

The cochineal-dyed cloth did not change with distilled water. Acetic acid lightened the red colour and dissolved the pigment, while ammonia changed the colour to purple and dissolved the pigment.

Madder and cochineal have a red colour, which can be distinguished by a solublity colour test. This test makes it possible to determine the type of dye, which


Fig. 9.6 Madder fabric in water (pH7)
No change


Fig. 9.7 Madder fabric in acetic acid (pH2)
Changed


Fig. 9.8 Madder fabric in ethanol
No change


Fig.9.9 Madder fabric in ammonia (pH12)
Changed


Fig.9.10 Indigo fabric in acetic acid (pH2)
Changed


Fig.9.11 Cochineal fabric in acetic acid
(pH2)Changed


Fig.9.12 Cochineal fabric in water (pH7)
No change


Fig.9.13 Cochineal fabric in ammonia
(pH12) Change

Table 9.1 Solubility of dyes in reagents Notation: X = insoluble

Dyes			Dyed fabric sample			99.6% Acetic acid (pH2)		Distilled water (pH7)		25% Ammonia（pH11）		Ethanol	
English	Species	Component	Colour	Fiber	Mordant	Fiber colour	Solution colour	Fiber colour	Solution colour	Fiber colour	Solution colour	Fiber colour	Solution colour
Dyer's madder	Rubia tinctoria L.	Alizarin, purpurin, xantho-purpurin, munjistin, pseudopurpurin	Red-orange	Silk	Alum（Al）	Orange	Light orange	×	×	Red	Pink	×	×
Indian madder	Rubia tinctoria L.	Alizarin, purpurin, xantho-purpurin, munjistin, pseudopurpurin	Red	Silk	Alum（Al）	×	×	×	×	Dark red	Very light pink	×	×
Japanese madder	Rubia akane Nakai L.	Purpurin, munjistin, pseudopurpurin	Red	Silk	Alum（Al）	×	×	×	×	Red	Red	×	×
Brazil wood	Caesalpinia sappan L.	Brazilin	Red	Silk	Alum（Al）	Orange	Pink	×	Pink	Light orange	Orange	×	×
Safflower, petal	Carthamus tinctorius L.	Carthamin	Pink	Silk	None	Light pink	Orange	×	×	Light yellow	Yellow	×	×
American Cochineal	Dacrylopius coccus Costa	Carminic acid	Red	Silk	Alum（Al）	Pink	Orange	×	Pink	Light pink	Pink	×	×
Armenian cochneal	Porphyrophora hameli Brandt	Carminic acid	Pink	Silk	Alum（Al）	Orange	Orange	×	×	Light purple	×	×	×
Lac	Kerria achinesis	Laccaic acid D	Pink	Silk	Alum（Al）	×	Light pink	×	×	Light pink	Light pink	×	×
Alkanet	Alkanna tinctoria L.	Alkannin	Purple	Silk	Alum（Al）	Light purple	Light red-purple	×	×	Light purple	Light purple	×	×
Shikon	Lithospermum euchromum L.	Shikonin	Purple	Silk	Alum（Al）	Light purple	Light purple	×	×	Light blue-purple	Light blue-purple	×	×
Shelfish purple	Rapana venosa, Valenciennes	Indigo bromine	Purple	Silk	Alum（Al）	Light purle	×	×	×	Light purple	×	×	×
Logwood	Haematoxylum campechianum L.	Haematoxylin, haematein	Purple	Silk	Tin（Sn）	×	×	×	×	Gray	Light gray	×	×
Japanese indigo	Persicalia tinctoria L.	Indigotin	Blue	Silk	None	×	Blue	×	×	×	Light blue	×	×
Indian indigo	Indigofera tinctoria L.	Indigotin	Blue	Silk	None	×	Blue	×	×	×	Light blue	×	×
Woad	Isatis tinctoria L.	Indigotin	Blue	Silk	None	×	Blue	×	×	×	Light blue	×	×
Indigo carmine	Synthetic dye	Indigo carmine	Blue	Wool	None	×	×	×	×	Blue-green⇒white	Light green⇒transparent	×	×
Prussian blue	Synthetic pigment	Iron(III) ferrocyanide	Blue	Wool	None	×	×	×	×	Light blue⇒white	×	×	×
Kihada, inner bark	Phellodendron amurense Rupr.	Berberine	Yellow	Silk	Alum（Al）	×	Light yellow	×	×	×	Light yellow	×	×
Turmeric, root	Curcuma longa L.	Curcumin	Yellow	Silk	None	×	×	×	×	Light yellow	Light yellow	×	×
Gardinia, fruit	Gardinia jasminoides Ellis	Crocin	Yellow	Silk	None	×	×	×	×	×	Yellow	×	×
Saffron	Crocus sativus L.	Crocin	Yellow	Silk	None	×	×	×	×	×	Yellow	×	×
Annatto, fruit	Bixa Orellana L.	Bixin	Yellow	Silk	None	Light yellow	Orange	×	×	Light orange	Light yellow	×	×
Haze	Toxicodendron sylvestre	Morindin	Yellow	Silk	Alum（Al）	×	×	×	×	Red-brown	Light red-brown	×	×
Kariyasu, leaf and stalk	Miscanthus tinctorius L.	Luteolin	Yellow	Silk	Alum（Al）	×	×	×	×	×	Light yellow	×	×
Weld, leaf and stalk	Reseda luteola L.	Luteolin, apigenin	Yellow	Silk	Alum（Al）	×	×	×	×	Light yellow	Light yellow	×	×
Cephalaria	Cephalaria procera Fisch and Lall	Luteolin, quercetin	Yellow	Silk	Alum（Al）	Light yellow	Yellow	×	×	Dark yellow	×	×	×

Dyes			Dyed fabric sample			99.6% Acetic acid (pH2)		Distilled water (pH7)		25% Ammonia (pH11)		Ethanol	
Chinese yellow bods, flower bud	Sophora japonica L.	Rutin, quercetin	Yellow	Silk	Alum (Al)	×	×	×	×	Orange	Orange	×	×
Onion skin	Allium cepa L.	Quercetin	Yellow	Silk	Alum (Al)	×	×	×	×	×	Light yellow		
Old fustic	Maclura tinctoria Gaud.	Morin, kaempferol	Yellow	Silk	Alum (Al)	×	×	×	×	Orange	Orange	×	×
French berries, fruit	Rumnus species	Kaempferol, quercetin, rhamnetin, emodin	Yellow	Silk	Alum (Al)	×	×	×	×	×	Yellow	×	×
Kobunagusa	Arthraxon hispidus Thumb.	Flavonids	Yellow	Silk	Alum (Al)	×	×	×	×	Dark yellow	Yellow	×	×
Imortel (Everlasting flower)	Helichrysum arenarium L.	Flavonids	Yellow	Silk	Alum (Al)	×	×	×	×	Dark yellow	Dark yellow	×	×
Fukugi, inner bark	Garcinia sebelliptica L.	Fukugetin	Yellow	Silk	Alum (Al)	×	×	×	×	Orange	Yellow	×	×
Myrica rubra, inner bark	Myrica rubra Sieb.	Myricetin, myricitrin	Brown	Silk	Alum (Al)	×	×	×	×	Red	Red	×	×
Pmonogranet, cortext of fruit	Punica granatum L.	Ellagic acid	Brown	Silk	Alum (Al)	×	×	×	×	Orange	Light orange	×	×
Gallnut		Gallic acid	Brown	Silk	None	×	×	×	×	Orange	Orange	×	×
Flower pod of aluns firma	Alnus firma L.	Tannic acid	Brown	Silk	None	×	×	×	×	Dark brown	Brown	×	×
Wallnut fruit peel	Juglandaceae species	Tannic acid	Brown	Silk	None	×	Light brown	×	Light brown	Dark brown	Brown	×	×

is difficult to determine by looking at the colour alone. This also shows the effects of acids and alkalis on the dye, and the conditions under which colour bleeding is likely to occur. It is important to know the characteristics of dyes in terms of storage and exhibition conditions, and various treatments.

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10 Dye Analysis 2 Identification of Natural Dyes by Thin-Layer Chromatography (TLC)

There are many reasons why a conservator or a curator wants to know about the dyestuffs used in the historic textile. Information might be sought on dating, origin original colour and appearance of the textile or for conservation treatments such as cleaning and preventive conservation measures such as display lighting.

Within dye analysis of historic textiles, one of the first step to identify the dye is by conducting a micro-chemical test (solubility test) and the next step is chromatography. Chromatography is a separation technique of non-volatile compounds. Among many chromatography methods, TLC (thin-layer chromatography) is suitable for mixtures of compounds that will dissolve in solvents and can be conducted with simple tools. It uses a plate of glass, plastic or aluminium coated with a thin layer of adsorbent material such as silica gel. Silica gel is often used for food packaging to absorb moisture and is a polar (water attractive) material. This plate is called a stationary phase. To separate a compound, a sample dissolved in a solvent is applied as a dot on the bottom of the plate. Then the plate is inserted into a glass container with a small amount of solvent mixture that is called a mobile phase. As the mixture is drawn up the plate by capillary action, the compound also runs up the plate and separates if more than one compound is present.

Natural dyestuff contains many compounds but not all of them bond will the fibre as dye. Qualitative analysis of dyes on historic textile is carried out by comparing the unknown with an authentic compound, such as alizarin, and an extract from a comparative dyed fibre, such as madder dyed on silk. The method of TLC analysis on historic textiles spread among conservators in the U.S. thanks to the German organic chemist Helmut Schweppe who conducted a workshop at the Smithsonian Institution during 1986-88[1-3]. A good text on studies on chromatography applied to

Fig. 10.1 TLC Dyer's madder
(Day light photography)

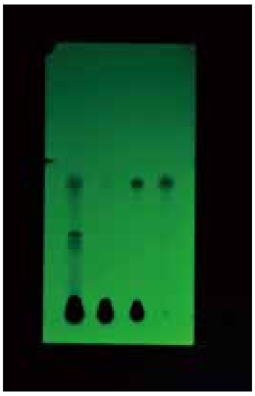

Fig. 10.2 TLC Dyers madder
(UV 245nm)

Fig. 10.3 TLC Dyers madder
(UV 365nm)

Identification of dyes on a red woollen textile with TLC
TLC Plate: Alugram™ SIL G/UV254 for TLC (Macherey-Nagel™)
Spot from left to right,
① Dyer's madder ② Alizarin ③ Purpurin ④ Unknown = Dyer's madder (matched with ② & ③)
Rf: ② Alizarin 0.89 ③ Purpurin 0.91
Eluent: ethyl acetate : methanol : formic acid : water (50:2:2.5:4)

dye analysis on historic textile is written by the Dutch conservation scientist Judith H. Hofenk de Graaf[4].

The principle of TLC is based on the differences in polarity and attraction force of the compound to the stationary phase (plate). For example, a normal silica gel plate is polar. Given two compounds that differ in polarity, the more polar compound has a stronger interaction with the silica. As a consequence, the less polar compound moves higher up the plate. By changing the solvent, the separation of the compounds can be adjusted.

Observation and investigation of dyed textiles

Learning the historical and cultural context of the textile, as well as careful examination of the fabric, is important before beginning testing[5]. Technical examination of the fabric will allow identification of the weave structure, warps and wefts, and whether the fabric is made with pre-dyed yarns or was dyed after weaving. Condition examination and deterioration phenomena will provide information about the fading, which may help to indicate the type of dye used.

Stage 1. Dissolving and extracting dyes

1.1 Dissolving authentic compounds (reference).

1.2 Extracting comparative dyes from sample fabrics (reference).

1.3 Extracting unknown dyes from the dyed textiles (reference).

Stage 2. TLC experiment

2.1 Prepare instruments and chemicals.

2.2 Separate the dye extracted with the TLC plate.

2.3 Calculate the distance the dye has travelled (delay factor Retardation Factor) Rf.

Stage 1. Dissolving and extracting dyes

Fig. 10.4 Adjustment of standard reagents and dyes

1.1 Dissolving authentic (known) compounds (colourants)

Pure compounds, such as alizarin and purpurin can be purchased from chemical suppliers. Dissolve both the comparative dye and unknown sample compounds in the same solvent. TLC is not quantitative analysis so taking a small amount of compound and dissolving it in 5-10 ml of solvent is acceptable. Solvent concentration of an authentic compound is calculated by the molar concentration. An example of a dilute solution for TLC practice is given here.

Example: Preparation of Alizarin standard reagent

Prepare 0.01 mol/L (10 M-3) of alizarin in 10 ml of methanol.

Authentic: Alizarin (CASRN 70-48-0) (Wako Chemicals)

Molar mass: 240.20 g/mol

Calculation	0.01 mol/L x 240.2 g/mol x (10 ml ÷1000 ml) = 0.02402 g
Preparation	Dissolve 0.024 g of alizarin in approximately 8 ml of methanol. Mix well and top up 2 ml making it to 10 ml.

Fig. 10.5 Extract the coloring matter from samples and dyes.

1.2 Extracting dyes

Crush dyes in a mortar and take 0.1g in a glass tube. Add drops of extraction agent and shake.

1.3 Extracting comparative dyes from sample fabrics

Extraction method from a yarn is the same with comparative dyeing fabrics and a historic textile. Solvents used differ according to the type of dyes.

1.3.1 Direct dye

Direct dyes such as vegetable tannins and curcuma dyes can be extracted from the fibre with methanol.

1. Put the sample yarn into a small glass tube.
2. Add several drops of methanol to the sample.
3. Warm the glass tube at around 30º C in an ultrasonic bath.

1.3.2 Mordant dye

Mordant dyes such as madder, red insect pigments, and flavonoid dyes are dyed on yarn as metal complexes (containing alum, iron, and tin as mordants). Therefore, in order to extract the dye, it is necessary to separate the metal complex by hydrolysis. If the dye cannot be extracted with only methanol, add 10% hydrochloric acid and methanol in a ratio of 1:1 or 2:1 (v/v)[6].

1.3.3 Vat dye

To dissolve indigo and dibromoindigo (shellfish purple) add several drops of N,N-dimethylformamide (DMF).

1.3.4 Mordant dye + blue (indigo) (purple, green colours)

As in 1.3.1 or 1.3.2, extract the mordant dye and pour out the extract into a glass test tube. Add one drop to two drops of DMF to extract the blue dye. The fibre will remain blue if indigo is present.

1.4 Sampling historic dyed textiles and extracting dyes

The amount of yarn required as a sample is around 1-2 cm(0.3-0.5 g). More samples may be necessary if the colour is pale. As this is a destructive test, photographic records of the historic textile, locations and samples are taken, before and after removing the sample. Remove any contamination from the yarn under the magnification of a stereo microscope. Give the sample an ID, weigh and photograph the yarn with a scale. Keep the sample in a sample bag labelled with the sample ID.

Fig. 10.6 Alminium (left) and glass (right) plates with silica gel.

Fig. 10.7 Separation chamber

Fig. 10.8 Micro pipets

Fig. 10.9 Solvents

Stage 2. TLC experiment

Tools and chemicals need to prepared in advance.

2.1 Selecting and preparing a TLC plate

A common stationary phase for TLC in dye analysis is a glass or aluminium plate pre-coated with silica gel. A type with fluorescence indicator. TLC plate with fluorescent will help to identifying the compound with UV light. Examples are Alugram* SIL G/UV254 for TLC (Machery-Nagel), TLC Silica gel 60F254, glass (Merck). Wear gloves and handle the plate with a flat end tweezer so as not to damage the surface.

2.2 Selecting and preparing a separation chamber

A separation chamber is a glass container with a well fitted cover and a flat bottom. The cover should close properly to keep the vapour in during the separation. Leaking of vapour can cause undesirable edge effects in the chromatogram. Inserting a filter paper will help keeping the equilibrium of the vapour in the container.

2.3 Selecting a capillary pipette

A capillary pipet is a fine glass tube used to apply a small amount (1-5 μ l) of sample on the TLC plate.

2.4 Selecting an eluent

Some solvents used in TLC are very toxic. Health and safety precautions must be taken when handling these chemicals. Work under a fume hood equipped with an organic vapour filter. Wear a lab coat, glasses and nitrile disposable gloves. It is preferable to select solvents with low boiling point, low viscosity, and low toxicity.

An eluent for the mobile phase is a mixture of polar and non-polar solvents which help to separate the compounds of the dye on the TLC plate. "Strong" solvents push the compounds up the plate, whereas a "weak" solvent does not cause them to move

Table 10.1 Natural dyes and TLC eluents[8-13]

Class of natural dyes（dye stuff）	Eluent
Anthraquinone (Dyer's madder) Brazilin (Sappan wood) Berberine (Phellodendron) Carthamin (Safflower)	ethyl acetate : methanol: formic acid : water (50:2:2.5:4) acetic acid : methanol: water (3:3:4)
Anthraquinone (Kermes, Lac, Cochineal)	methanol: water: 1-butanol (7:3:1)
Flavonoid (Cephalaria, Immortelle, Weld, Kariyasu)	ethyl acetate: isopropanol: water (100:17:13) (2-propanol)
Alkannin (Alkanet), Shikonin (Shikon)	

far. Eluents can be arranged by their polarity in 'eluotropic strength scales'. The order of strength/weakness depends on the coating of the TLC plate. For silica gel, the eluent strength increases in the following order :

(Weakest) n-pentane < n-hexane < n-heptane < cyclohexane < carbon tetrachloride< benzene/toluene < trichloromethane (chloroform) < dichloromethane < diisopropyl ether (dimethyl ether) < n-butanol < diethyl ether < nitromethane <acetonitrile <1-butanol <2-propanol < ethyl acetate< 1-propanol < acetone< ethanol < dioxane < tetrahydrofuran < methanol < pyridine < water < acetic acid < formic acid (Strongest).

Experiment

1. Preparing the separation chamber with eluent


Fig. 10.10 Pre-wash the plate by running the plate with the eluent.

1.1 Insert a sheet of filter paper in the separation chamber in a vertical position.

1.2 Add the eluent just to cover the bottom of the container less than 1 cm deep.

1.3 Close the chamber and wait until the eluent runs up the filter paper and the container is saturated with the solvent vapour.

2. Preparing the TLC plate(pre-washing)

2.1 Wash the plate by running the plate with ethanol or the eluent once in the separation chamber. Note the top and bottom of the plate. Dry the plate well for good results.

2.2 Mark a horizontal line with a pencil 1 cm above the bottom of the plate.

2.3 Mark areas to spot on the line 1cm apart.


Fig. 10.11 Dry the plate on a heater.

3. Applying samples to TLC plate

Apply a drop of sample on the marked area of the plate with a micro glass capillary pipette (1-5 μ l). The ideal diameter of a spot is around 2 mm.


Fig. 10.12 Apply the sample on the plate with a micro pipet.

Fig. 10.13 About 5 mm of the eluent is placed in the bottom of the separation chamber, and filter paper is placed so that the vapour is at the top of the container. Prop the TLC plate inside, cover and unfold.

4. Running the TLC plate in the separation chamber

Insert the plate into the separation chamber and close the lid. The eluent should be below the bottom pencil line of the plate. As the eluent is drawn up by capillary action, the compound will also move up and separate. When the solvent reaches 1 cm below the top of the plate, take out the plate and immediately mark the solvent front with a pencil.

Fig. 10.14 Observe the spot with a UV lamp that switches between 245 nm and 365 nm.

5. Detection

Observe the plate under daylight and UV light (around 245 nm and 368 nm). Some spots will fluoresce or become dark which will help detect the spots. Mark the spots with a pencil. UV protective goggles must be worn, and hands must be covered with gloves.

To enhance the detection of the spots, the plate may be sprayed or immersed in a 5% potassium hydroxide solution in methanol. The colours turn dark brown but will fade after a while. This is an option if the spots are not clear and there are other detectors.

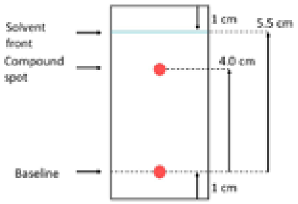

Fig. 10.15 Calculation of the Rf value

6. Reading the result

Check the compound spots under daylight and UV light (245 nm, 365 nm) and circle the spots with a pencil. Measure the distance between the solvent front and the centre of the spots. Calculat the retardation factor (Rf) value which is defined as the ratio of the distance travelled by the centre of a spot to the distance travelled by the solvent front.

Distance of the compound spot ÷ Distance of the solvent front = Rf

Example: 4.0÷5.5 = 0.72 A. Rf 0.72

Given the same experimental condition, the Rf value allows us to compare compounds and judge whether the unknown sample matches with the reference samples to identify the dye of the historic textile.

Table 10.2 Characterization of solvents used in TLC: highly polar (top) to non-polar (bottom)[14]

Solvent	Compound	Molecular weight	Boiling point (℃)	Melting point (℃)	Solvent density (g/mL)	Solubility to water	Dielectric constant (epsilon ε_r)	Flash point (℃)
Distilled water （Polar）	H_2O	18.02	100	0	0.998	-	78.36	-
Formic acid	CH_2O_2	46.025	100.75	8.4	1.2196	soluble	58.50	-
N,N-dimethylformamide (DMF)	C_3H_7NO	73.09	153	-60.48	0.9445	soluble	36.71	58
Methanol	CH_4O	32.04	64.6	-98	0.791	soluble	32.66	12
Ethanol	C_2H_6O	46.07	78.5	-114.1	0.789	soluble	24.55	13
Acetone	C_3H_6O	58.079	56.05	-94.7	0.7845	soluble	20.56	-20
1-propanol	C_3H_8O	60.1	97	-126	0.803	soluble	20.45	15
2-propanol	C_3H_8O	60.1	82.5	-89	0.786	soluble	19.92	12
Methyl ethyl ketone (2-butanone, MEK)	C_4H_8O	72.11	79.6	-86.6	0.7999	soluble (25.6)	18.11	-9
1-butanol	$C_4H_{10}O$	74.12	117.7	-89.8	0.800	soluble	17.5	35
Pyridine	C_5H_5N	79.1	115.2	-41.6	0.982	soluble	12.91	17
Tetrahydrofuran (THF)	C_4H_8O	72.106	65	-108.4	0.8833	soluble (30)	7.58	-14
Methyl acetate	$C_3H_6O_2$	74.08	56.9	-98	0.932	soluble (24.4)	6.68	56.9
Acetic acid	$C_2H_4O_2$	60.052	118	16.6	1.0446	soluble	6.15	39
Ethyl acetate	$C_4H_8O_2$	88.11	77	-83.6	0.895	soluble (8.7)	6.02	-4
Butyl acetate	$C_6H_{12}O_2$	116.16	126	-74	0.88	solubule	5.01	23.9
Chloroform	$CHCl_3$	119.38	61.2	-63.4	1.4788	insoluble (0.795)	4.81	-
Tolulene	C_7H_8	92.14	110.6	-93	0.867	insoluble (0.05)	2.38	4
n-hexane	C_6H_{14}	86.18	69	-95	0.659	insoluble (0.014)	-	-22
Ether (petroleum) Non-polar	-	-	30-60	-40	0.656	-	-	-30

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Chapter 3

Storage and Display of Textiles

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Storage and Display of Textiles

11 Storage & Display

Priorities for the preservation of museum textiles are to provide physical support, protect from dust and light, allow visual access, and minimize handling. The type of storage system for a single textile or group of textiles depends on the material make-up, condition, form, its use/ role (display, loan, transportation etc.), location of storage and space. Materials for covering or supporting the textile provide the first layers for protection and should be chosen and designed to ensure the stability of the textile[1].

A mount is a physical support on which an artefact is laid upon. Mounts are required for the safe handling, storage, and display of artefacts. Criteria for storage and display materials of artefacts as well as various mounts, from simple structures to advanced structures, are introduced in this chapter. When constructing a storage system for a fragile textile, it is recommended to design a system with the textile's future display in mind, which will reduce direct handling and handling time. Anoxia storage, which can slow down material deterioration and insect and biological activity, is also explained at the end of this section.


Fig. 11.1 Display at Saga University Art Museum


Fig. 11.2 Storage of collections

1. Environmental Management

The composition of soil on historical textiles is likely to result in contamination by pests. Therefore, it is important to ensure that daily maintenance of museum artefacts is carried out, as well as periodical inspection of storage rooms and exhibition rooms, regulation of temperature/humidity and cleaning. Integrated pest management (IPM) involves cleaning the floors and shelves every week as part of the inspection process as well as placing insect traps and controlling the infestation of pests[1].


Fig. 11.3 Themo-hygrograph and data logger


Fig. 11.4 Moveable storage

1.1 Temperature and relative humidity

When the room temperature rises above 20 ℃ and humidity increases above RH65%, mould and microorganisms become active. The rise in temperature and humidity can cause the deterioration of fibres and accelerate the discolouration of textiles. To evaluate the environment of the museum, the temperature and humidity inside the exhibition rooms and storage rooms should be measured and recorded with a thermo-hygrograph and/or a data logger. The weather, temperature, and humidity of outside air should also be measured and recorded throughout the year. It is also helpful to examine the passage of air and the capacity of the air conditioning system, to ensure that it is possible to maintain stable temperature and humidity levels throughout the year

2. Storage

It is advisable to position storage furniture with plenty of space in between so that they do not block the passage of air, and to make cleaning easily accessible. Storage furniture should be anchored onto the floor or wall to prevent overturning during an earthquake. Artefacts placed on shelves should be fastened with a rope, cotton tape, or fishing line to prevent them from falling off the shelves. Large-scale works of art should be tied to the wall.

Number the storage units and allocate a set space for each object. The location of the object is recorded in the object record sheet and/or database so that the object may be accessed with ease.

3. Selecting materials for storage and display

Criteria for materials used for storage and display of textiles are acid-free (pH neutral) and chemically stable. Many materials used in conservation, storage and display have been tested by the 'Oddy test'. This experiment uses a variety of metal coupons to test for volatile gases being released from the material during accelerated heat aging[2-3]. The results follow the general rules described below[4-5].

- Avoid wool products (sulphur-containing wool tarnishes metals and attracts insects).
- Use water-fast products (prevents dye and pigment bleeding).
- Use light-fast products (prevents colour fading).
- Wash fabrics before use to remove soiling, mechanical oil, and sizing.
- Use undyed, unbleached fabrics such as cotton and polyester.
- Use long-lasting neutral pH paper products.
- Use long-lasting neutral pH adhesives.
- Use hardwood for wood products.
- Seal acids and resins of wood products.

3.1 Support board

Material description	Product name	Manufacturer or distributer
Archival hardboard Made of wood pulp with a buffering agent (calcium, magnesium etc.) and adjusted to around pH 8.5.	AF Hardboard	Tokushu Paper Trading (Japan)
	Premier™ Archival folding box-board	Conservation by Design (U.K.)
Corrugated archival board Made of wood pulp with a buffering agent (calcium, magnesium etc.) and adjusted to around pH 8.5.	Archival board	Tokushu Paper Trading (Japan)
	Premier™ Archival fluted boxboard	Conservation by Design (U.K.)
	Dur® Archival corrugated board	Preservation Equipment (U.K.)
	Heritage corrugated board	Talas (U.S.A.)
Archival mat board Made of cotton pulp without any buffering agent and adjusted to around pH 7.0.	Puremat	Tokushu Paper Trading (Japan)
	Timecare™ cotton museum mount board	Conservation by Design (U.K.)
	100% rag mounting board	Preservation Equipment (U.K.)
	Rising® museum mat board	Talas (U.S.A.)
Polypropylene/ polyethylene corrugated board	Corrugated plastic sheets Core-X® Poly-flute®	Preservation Equipment (U.K.)
	Coroplast®	Talas (U.S.A.)
Archival paper honeycomb board A honeycomb structure is sandwiched between two sheets of paper made of wood pulp with a buffering agent, adjusted to mid-alkali.		
	Tycore® (Perna/Dur® Buffered Bristol board)	Conservation by Design (U.K.) Talas (U.S.A.)
	Honeycomb panels	Preservation Equipment (U.K.)
Aluminium honeycomb board		
	Aluminium centered honeycomb board	Conservation by Design (U.K.)
Archival paper tubes	Rolled storage tubes	Preservation Equipment (U.K.) Talas (U.S.A.)

3.2 Padding material

Material description	Product name	Manufacture or distributer
Polyester felt (needle punch felting, with no resins)	Polyester batting/ wadding	Preservation Equipment (U.K.)
	Polyester felt	Preservation Equipment (U.K.)
	Pellon	Talas (U.S.A.)
Spun-bond polyester non-woven fabric	Reemay® Hollytex® Bondina®	Conservation by Design (U.K.) Preservation Equipment (U.K.) Talas (U.S.A.)
Polyethylene foam	Plastazote®	Conservation by Design (U.K.)

* Do not use untreated cotton padding because it is highly moisture-absorbent.

3.3 Covering material

Material description	Product name	Manufacturer or distributer
pH-neutral tissue paper	Acid-free tissue	Conservation by Design (U.K.)
	PEL tissue	Preservation Equipment (U.K.)
	Acid-free unbuffered tissue	Talas (U.S.A.)
pH-neutral archival paper (non-buffered)	Pure Guard	
	Heritage Archival pHotokraft™ unbuffered paper	Conservation by Design (U.K.)
	Bond paper	Talas (U.S.A.)
Woven and knitted cotton and polyester fabrics	Cotton fabric, polyester felt	
	Cotton tape	
	Stockinet® (tubular knit, cotton, polyester)	3M (U.S.A)
Woven and knitted cotton and polyester fabrics	Tyvek®	Conservation by Design (U.K.) Preservation Equipment (U.K.)
Clear polyester sheet film	Lumirror® Lumirror® X53 (anti-static)	Toray (Japan)
	Polyester roll Melinex®	Conservation by Design (U.K.) Preservation Equipment (U.K.)
	Mylar®	Talas (U.S.A.)
Aluminized polyethylene and nylon barrier film	Marvelseal® 360	Preservation Equipment (U.K.)
100% polyester hook and loop fastener	Magic Tape® (A/hook, B/loop)	Kuraray (Japan)

* Wash well and remove sizing (starch/ PVA adhesive).

**When using coloured fabrics, check for fastness against water and light for dyed fabrics.

3.4 Adhesive

Material description	Product name	Manufacture or distributer
Methyl cellulose (MC) type The viscosity is expressed as cps(centipoises(s)=1/100poise). The larger the cps the higher the viscosity becomes in the same aqueous concentration. When adhering papers together, a 5-10% solution of around 4000cps is sufficient.	Metrose	Shinetsu Chemical (Japan)
	Tylose® MH	Sigma Aldrich
Hydroxypropyl cellulose type When adhering paper and textile together, a 5-10% solution is sufficient.	Klucel G	Talas (U.S.A.)
Acrylic type This adhesive is used to adhere thick papers together, and in diluted form Lascaux is used to coat fabric supports (like nylon net and silk crepeline) which can be heat set.	Lascaux® acrylic adhesive 498 HV, 498-20X Paraloid® B72	Conservation by Design (U.K.) Preservation Equipment (U.K.) Talas (U.S.A.)
Polypropylene type This hot melt adhesive is used to adhere polyethylene foams together.	3M Scotch-Weld™ hot melt adhesive #7399	3M
Archival double sided tape	3M™ # 415 3M™ Gold adhesive transfer 3M™# 889 mounting tape Gudy® 0 (#870) Gudy® V (#831)	Conservation by Design (U.K.) Preservation Equipment (U.K.) Talas (U.S.A.)
Archival tape	Filmoplast® P90 3M#887 tape	Conservation by Design (U.K.) Preservation Equipment (U.K.) Talas (U.S.A.)

*Use an adhesive that has been tested for long term use.

Fig. 11.5 Aluminium base and UV cut, anti-static, low-reflection acrylic lid

Fig. 11.6 Wooden rods are painted with an acrylic coating and covered with fabric

3.5 Glazing

- Polymethylmethacrylate (Perspex®, Plexiglas®).
 A UV cut, antistatic, low reflection type is preferred.
- Glass, with UV cut type is preferred.

3.6 Wood products

- Hardwoods such as poplar, magnolia, and ash.
- Seal acids and resins with a plastic laminated aluminium barrier foil (Marvelseal® 360).
- Coat with water-based acrylic emulsion paints.

*Do not use oil-based paints as they emit high levels of organic solvents.

4. Method of Storage

Since museum textiles are kept in storage for a long time it is important to incorporate the concept of preventive conservation, maintaining the physical condition of the textile by using chemically stable materials. If museum textiles are treated in the same way as everyday wear and folded away in a drawer, creases and wrinkles become fixed in time, difficult to remove, and eventually lead to splits and tears. Suspending costumes on a commercial hanger will also result in distortion. Implementing preventive measures, such as shoulder pads, will help to maintain the garment's shape. When planning storage for textiles, flat storage is given priority, then rolled, and lastly folded and hung are considered. The storage system will depend on each institution's needs and policies.

4.1 Horizontal (flat) storage

The textile should be individually wrapped in acid-free paper or pre-washed cotton cloth that has had the sizing removed. It should then be placed on a card or board for support and handling and stored inside a storage case/box. Textiles should not be stacked directly on top of each other in a storage container and should be organized so that each can be easily retrieved without disturbing the rest. Small and lightweight fragments can be arranged into compartments on a tray between thick spacers and arranged into several layers within a storage box. All storage containers should be labelled on the outside with an object I.D.

Fig. 11.7 Storage box

Fig. 11.8 Label

Fig. 11.9 Upper layer

Fig. 11.10 Textile on a padded board

Fig. 11.11 Lower layer

Fig. 11.12 Folding the sides of the upper layer provides space for the lower layer

① Wrap the textile with pH-neutral paper.

②Clear polyester envelopes will allow visual examination on both sides. A non-static polyester sheet (such as Lumirror® X58) is recommended. An ultrasonic heat sealer is necessary to cut and seal polyester envelopes for a good finish. An alternative method is to machine stitch the sides or use archival double-sided tape (3M® #415).

③ An archival mat board with a clear polyester cover will provide support and visibility.

④ If the textile has pleats and folds, inserts of rolled tissue or long paddings should be added to prevent distortions and sinking areas. The same applies when storing the textile folded.


Fig. 11.13 Storage drawer


Fig. 11.14 Wrap with pH-neutral paper


Fig. 11.15 Envelope shaped cover


Fig. 11.16 Window mat

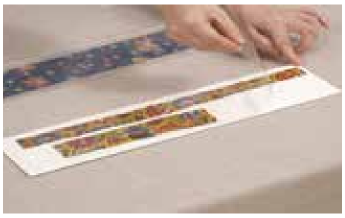
Fig. 11.17 Clear polyester sheet cover


Fig. 11.18 Polyester sheet envelope

4.2 Rolled storage

Textiles with embroidery, lining, piled velvets, and carpets are better rolled with the obverse side out so that any creases occur on the reverse side. Thin paper or padding should be inserted to level uneven surfaces to facilitate the rolling. Once the textile has been rolled onto the tube it should be covered with acid-free paper or cotton cloth and placed in a storage case/ box. The tube should be supported on both ends and suspended, to prevent any crushing along the bottom.

In Europe, North America and Japan, archival acid-free paper tubes can be bought from suppliers. If it is not possible to obtain the above type of tube, a ready-made paper tube (often acidic paper) wrapped in aluminium foil, to minimize oxidization, can be used as a substitute. It is also possible to make a tube using thick polyester film which is chemically stable.


Fig. 11.19 Kimono fragment (mid 17th century)


Fig. 11.20 Roll with pH-neutral paper roller and tissue paper


Fig. 11.21 Cover with pH-neutral paper


Fig. 11.22 Storage box made of archival board


Fig. 11.23 Nabeshima carpet (20th century)


Fig. 11.24 Cover with washed cotton fabric

4.3 Folded storage

When folding textiles for storage, it is advisable to keep the number of folds minimal. Paper and padding material should be placed in between the textile to alleviate the angle of the folds. Textiles should then be put on an archival board and placed in a box.

In Japan, traditionally kimonos are kept in a paulownia box or chest as this wood emits little volatile organic acids when it is seasoned well. In museums, this storage method has continued as part of preservation of living heritage of kimono culture.


Fig. 11.25 Long sleeve kimono


Fig. 11.26 Insert cushions between folds


Fig. 11.27 Traditional kimono fold


Fig. 11.28 Place in a board underneath.


Fig. 11.29 Place in Japanese covering paper


Fig. 11.30 Storage in a paulownia box

4.4 Hanging storage

Jackets and garments in good condition may be stored on a clothes hanger. A normal hanger may stress the shoulder area and distort the shape of a garment. Thus, a padded hanger is advisable to help keep its shape. Garments often have buttons and other decorations, and to prevent contact, each garment must be covered with a bag made of washed cotton or non-woven polyester fabric which permits air circulation.


Fig. 11.31 Aluminium clothes hanger


Fig. 11.32 Pad the hanger with polyester felt and knit fabric


Fig. 11.33 Cover the costume with non-woven fabric allowing air circulation

5. Mounting for storage and display

5.1 Padded board

For display, a fabric-covered mount is preferable over a smooth board. The friction of the fabric holds the textile in place, preventing movement, and providing an aesthetic visual effect. This method is suitable for flat textiles in relatively good condition which are to be displayed horizontally or with a slight. Design the board by adding about 5 cm to the size of the work as a handle (handling edge) so that fingers do not hang on the work.


Fig. 11.34 Handling edge


Fig. 11.35 Armenian lace


Fig. 11.36 Armenian carpet bag

5.2 Stitched mount/framing

Stitching the textile onto a padded mount will hold it in place but this is an interventive technique which should be undertaken by a textile conservator. This method is only suitable for textiles in good condition which are to be displayed slanted or vertically, transported or framed. When framing a stitch mount, make sure that the glazing does not come into contact with the textile. Place a spacer or a window mat between the frame and the textile.Place spacers or window mats between the forehead and the textile so that the tiles do not touch the textile. Commercially available foreheads are coated with acrylic paint twice on the inside to reduce organic acids. The trick is to use neutral thick paper.


Fig. 11.37 Stitch with long and short stitches


Fig. 11.38 Place a window mat between the glazing and textile


Fig. 11.39 Replace the backboard with archival board

5.3 Recessed/cavity system

Fragile textiles should be stored in a recessed/cavity storage system which restricts movement and prevents crushing[6-7]. The size of the cavity should be slightly larger and thicker than the textile dimensions. Basic cavity storage is made with a window mat and a baseboard. Its depth may be achieved with thick material such as polyester foam or polyester felt. Covering the base with fabric will prevent the contents from shifting and being crushed when moved. A recessed cavity system may be adapted for the display of fragile textiles by covering it with mounting fabric. Make a paper template of the textile by marking the outline and transfer the template onto a mat board or sheet of polyethylene foam. Cut out the shape. Trace the template onto a baseboard and punch interval holes along the marking line to be used as stitching holes. Cover the top and bottom board/foam with fabric and stitch along the edges of the window to hold the fabric in place. Lastly, fold back the excess fabric to the back of the baseboard and adhere it. This type of mount is only suitable for horizontal or slight slant display. Place a lid on the mount for protection. An acrylic lid will allow viewing.

Fig. 11.40 Recessed cavity mount covered with fabric

Fig. 11.41 The cavity prevents the textile from sliding

Fig. 11.42 An acrylic lid protects the textile and also allows viewing. Use UV cut, low reflectance, anti-static acryl cover

Fig. 11.43 An aluminium base and acryl lid case

5.4 Double-sided glass/ acrylic mounts

Archaeological textiles have often been mounted between two sheets of glass or acrylic sheets for support and research access to both sides. However, this type of mount is only suitable as a short-term solution. Past case studies have revealed that condensation, slipping and textile adhesion to glass occur when textiles are left in long-term storage in double-sided glass or acrylic mounts. It is advisable to use the friction of a mounting fabric and acrylic glazing material to hold the textile in place, although the disadvantage is that the reverse side cannot be seen. A good photograph can always supplement the information for the visual study of the reverse side.

Fig. 11.44 Double sided glass mount

5.5 Pressure mount

A pressure mount uses the friction of the mounting fabric and the glazing material (acrylic) to hold a textile in place without stitching[8] Padding (thin polyester felt) behind the mounting fabric provides cushioning for the textile. One or more layers of padding, graded in size, should be placed behind the mounting fabric for even cushioning. Acrylic glazing will bow when placed vertically. Thus, for large or thick textiles, padding should be elevated so that the centre becomes slightly higher than the surrounding area. Pressure mounting is a treatment option to be considered before an adhesive treatment for a fragile textile that may be damaged if left exposed. Pressure mounts are also suitable for short-term exhibitions or loans of moderate to small-sized flat textiles. Regular acrylic glazing is often static and can lift fibres from a brittle textile. It is advisable to use anti-static and UV-reflecting acrylic glazing, with the surface, wiped with alcohol. A cationic surfactant can also cut static electricity. Since acrylic sheets are easily scratched use lens tissue when wiping.

The maximum size of a pressure mount will depend upon the availability of the size of the acrylic sheet. It is advisable to use hardwood, such as poplar, magnolia, and ash for the stretcher as a base to screw down the acrylic sheet. Seal the wood with an aluminium sealing material layer, polyurethane or emulsion paint and make sure that they have completely evapourated before assembling the textile in the frame.

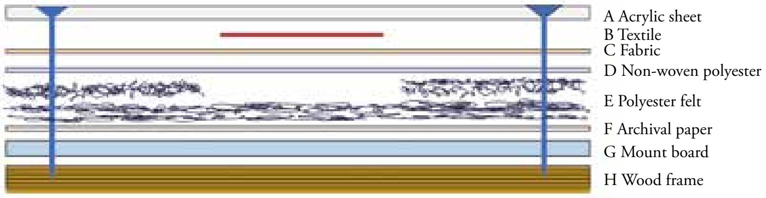

Fig. 11.45 A cross-section of a pressure mount (single galzing)

① Single galzing

Fig. 11.46

Fig. 11.47

Fig. 11.48

Fig. 11.49

Fig. 11.50

Fig. 11.51

② Double-glazing pressure mount systme


Fig. 11.52


Fig. 11.53


Fig. 11.54


Fig. 11.55


Fig. 11.56


Fig. 11.57


Fig. 11.58


Fig. 11.59


Fig. 11.60


Fig. 11.61


Fig. 11.62


Fig. 11.63


Fig. 11.64


Fig. 11.65


Fig. 11.66

① Single glazing system

Fig.11.46 - 11.51

Neutral pH cardboard is used for the baseboard of the pressure mount. Polyester felt is layered and areas for the textile to be inserted are cut out. The surface is covered with cotton fabric. An acrylic sheet is placed over and secured with wood screws. It can be displayed in a wooden frame or acrylic case.

② Double glazing system

Fig.11.52 - 11.66

Fix the perforated aluminium plate to the pedestal of the pressure mount. Laminate with polyester felt. Hollow out the polyester felt to the correct thickness in a shape that matches the textile. Cover with thin felt and cotton cloth to eliminate steps. Place the dyed fabric in the recess and fix the acrylic plate in place. Place the window mats and glazing, and frame them.

5.6 Three-dimensional mount/ mannequin/ kimono stand

Three-dimensional textiles, such as hats, will require an internal mount. A mannequin is another form of mount that supports the weight of the object rather than simply laying flat9. A mount may be constructed from soft polyethylene foam, polyester batting or felt and covered with cotton fabric or knit. The internal mount is then attached to the base for handling and stored in an individual box. A mannequin for displaying a costume is also one of the three-dimensional mounts. Since the clothing is worn on the human body, the three-dimensional mount helps the interpretation of the costume and enhances the exhibition effect[9]. Covering the wooden poles used to display the kimono with polyester knit and decorative cloth will ensure a safe and high-quality display.

Fig. 11.67 Pad the mannequin

Fig. 11.68 The costume is supported by the padded mannequin

Fig. 11.69 Covering the pole will enhance the safety and the visual presentation of the textile

Fig. 11.70 Insert a collar support in the slit of the pole

6. Oxygen-free (anoxia) storage


Fig. 11.71 Anoxia deactivation of pests and storage. Courtesy of Joshibi University of Art and Design Art Museum

Textiles with advanced fibre degradation, especially those which have high levels of transition metals, such as iron and tin that accelerate the material degradation, may be placed in an anoxia storage system to suppress chemical reactions. Some museums use this method for general storage where the storage facility is not sufficient to protect its collection from environmental damage[10]. Studies show that materials such as Prussian blue will change colour in an anoxic environment, but many other materials are not affected[11]. Anoxia treatment is also used for pest fumigation[12]. Depending on the type of pest, anoxia treatment at 25-30°C, for a duration of three weeks, is proposed as a guideline[13].

6.1 Oxygen-free storage using RP System[*14]

RP=Revolutionary Preservation
Ageless & RP system® (Mitsubishi Gas Chemical) is an anoxia packing system in which the oxygen level is kept below 0.1% for around 3-4 years.

Fig. 11.72 Place the agent, silica gel and oxygen indicator in the Escal film.

6.2 Tools and equipment

- RP agent®

Choose an RP agent according to the materials of the object. Use the material within 30 minutes of opening and then seal. The RP agent will last for 6 months.

① RP-A type (anoxia & dehumidification, suitable for metal objects) Air volume: RP-1A (100ml), 3A (300ml), 5A (500ml), 20A (2000ml)

② RP-K type (anoxia, suitable for non-metal objects) Air volume: RP-3K (300ml), 20K (2000ml)

Fig. 11.73 Seal the bag

- Gas barrier bag (PTS bag, Escal film®)

PTS bag or Escal film* is a high-grade barrier material. The smooth face is the inner side. The film contains a thin layer of glass. This thin layer will form cracks if bent. If it is kept intact, the film may be used repeatedly and wiped with alcohol for cleaning in between.

- Oxygen indicator, humidity indicator, silica gel, heat sealer, cotton gloves

6.3 Process

1. Cut the barrier bag according to the size of the object.
2. Calculate the amount of RP agent® according to the volume of the bag.

Length x width x height (cm) ÷ RP package (ml)

e.g. To use RP-20K with a reduction in air volume of 2000 ml

85 x 50 x 3 cm ÷ 2000 ml = 6.375 ml A. 7 packages

3. Insert the object, RP agent®, oxygen indicator, humidity indicator, and silica gel into the Escal film® bag. All indicators should be attached to the bag with tape so that they are easily visible.

4. Heat seal the Escal film® with a heat sealer at a temperature of 120 ℃. If the temperature is too low the Escal film® will delaminate, but if the temperature is too high, it will melt, harden, and crack. A good seal will have a clear line. Remove bubbles by reheating the area vertically. Pressing sealed areas with gloved fingers will help.

5. When the oxygen indicator turns from blue to pink, anoxia is complete. If silica gel is not used, the humidity level within the film will be the same as when it was sealed.

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12 Display Lighting

The display of artworks plays a significant role in a museum's education activity, consequently; it is unavoidable that textiles will be exposed to display lighting. Light accelerates the deterioration of fibres and dyes. Display lamps are often chosen according to the exhibition space and lighting design. A conservator should be able to advice which lamps reflects the colours well but also emit low amounts or excludes ultraviolet radiation (UV) or infrared radiation (IR)[1]. If the above criteria are met, the deterioration of textiles due to display can be minimized and a balance between display and conservation can be achieved within conservation management.

Halogen lamps and white fluorescent lamps are often used as a light source in exhibitions. Recently, white LED lamps have also begun to be used. Previous studies show that when a dyed fabric is exposed (for the same period and same luminance) to two white fluorescent lamps, one with UV and one without UV radiation, the dyed fabric will discolour approximately 20% less under the lamp without UV radiation[2]. This result is caused by the relationship between the short wavelength in the UV regions and the degradation of chromophores. Criteria required for museum lighting, which is not just limited to textiles, is the use of lamps which do not emit UV radiation. If it is not possible to obtain these types of lamps, a film which blocks UV radiation should be used to cover the acrylic and glass display cases. If this cannot be implemented, fading can be prevented by keeping luminance at a low level and the amount of energy absorbed by the chromophores kept minimal. When selecting a lamp, the colour temperature is one important indicator. Daylight colour lamps provide a good reflection of colours and have a wide distribution of visible radiation similar to sunlight. The light bulb colour lamp distributes long wavelengths and causes less fading. When taking into consideration the colour temperature (K=Kelvin), lamps with tungsten colour that are 2900K can minimize fading compared with daylight colour lamps that are 5000 K. Lamps with high colour rendering index, Ra 80-100, are suited for museum lighting[3].

The International Commission on Illumination (CIE) has divided the responsivity of museum artefacts to light into 4 stages. It is based on the blue wool standard (light fastness class) and issued a reference standard for the annual accumulated exposure of luminance of museum artefacts. Textiles' luminance should be limited to 50 lx from a light source which does not emit UV radiation and annual accumulated light exposure should be limited to 15,000 lx/hr•yr[4]. This means 8 hours of 50 lx per day, 6 days per week for a period of 6 weeks.

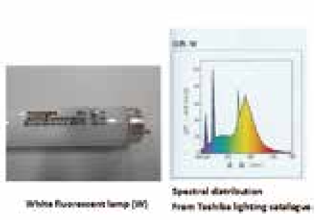

Fig. 12.1 White fluorescent lamp

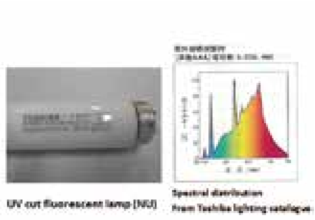

Fig. 12.2 UV cut white fluorescent lamp

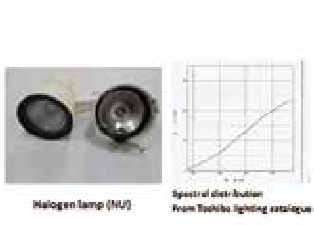

Fig. 12.3 Halogen lamp

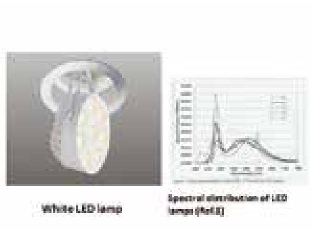

Fig. 12.4 White LED lamp

Fig. 12.5 Light meter

Table 1. CIE recommendation of the annual maximum exposure in relation to light responsivity of museum materials (TC:157:2004)[5]

Responsivity category	Blue wool standard	Limiting illuminance (lx)	Limiting exposure (lx・hr/yr)
1. No responsivity Mineral pigments	-	-	-
2. Low responsivity High-quality modern pigments	7-8	200	600,000
3. Mid responsivity Light fast natural dyes, above grade 4.	4-6	50	150,000
4. High responsivity Fugitive natural dyes.	1-3	50	15,000

Fig. 12.6 Lighting practice at Saga University Art Musuem

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Textile Conservation

Chapter 4

Degradation of Textiles and Conservation-Restoration

Chapter 4

Degradation of Textiles and Conservation-Restoration

13 Condition Assessment: Degradation of Fibres & Dyes

Textile conservators encounter textiles with a wide variety of fabrication types, dates, and cultures. Historic textiles have been produced and used in various eras and cultures and contain signs of wear and tear, creases, body secretions, food remains, dust, dirt, sand and insects. Fibres in textiles can lose their pliability and at times can even be reduced to a powdered state. The first stage in the conservation maintenance of textiles is to carefully examine the textile. The aim is to understand the materials and manufacturing techniques used in the textile and assess its condition and degradation factors. This knowledge is necessary to decide what conservation measures should be taken. If a decision is made that the textile requires attention, a conservation/restoration plan is laid out and conservation measures are implemented.

Fig. 13.1 18th-century French textile containing staining, tears, frayed yarns, folds, and fading.

1. Physical and mechanical damage

Damage to textile materials is caused by many factors. Signs include the following:

- wear or fibre degradation → tears
- pulling → elongation, splits
- abrasion → surface distortion
- strong folds and creases → cracks and splits
- cutting out areas, use of sharp tools → sharp cuts
- soiling, staining → discolouration.

2. Photo-chemical and thermo-chemical damage

Damage to materials is caused by exposure to light and/or heat. The extensity of damage depends on exposed wavelengths, intensity, and duration. This type of damage is cumulative and irreversible. For example, continued heating even at relatively low heat for an extended period will result in acid hydrolysis of fibre and lead to carbonization (slow burning effect). Signs of damage include;

- fading and discolouration of colours
- yellowing of fibres
- tears/loss of tensile and tearing strength
- dryness of fibres
- embrittlement and/or powdering of fibres
- distortion of the shape
- loss of sheen of fibres.

3. Chemical damage

Chemical damage in materials is caused by contact with volatile acids or alkalis, or by the inherent chemical stability of materials. For example, materials may encounter acids released from wooden storage shelves or be exposed to alkalis from building construction materials, such as cotreat. Textiles may have been dyed with an iron mordant or treated with tin weighting. Chemical reactions occurring in the materials may lead to further chemical reactions, accelerating the material's deterioration. Visual signs of damage are as follows;

- changes in colour
- changes in material texture
- odour
- an element of the material may be completely voided/missing

4. Biological damage

Fig. 13.2 Pest damage on wool fabric.

Textile materials, especially animal and vegetable proteins, such as wool, silk, leather, and starch, are attacked by insects and fungi. Biological activity is encouraged by high humidity (above 60% RH), high temperatures (above 25℃), darkness, stagnant air, and soiling. Signs of damage include;

- musty odour.
- presence of black or white powdery growth, multicoloured stains.
- small, irregularly shaped bitten holes in textiles.
- presence of live insects, larval skin, webbing, and insect excreta.

5. Fibre and degradation pathways

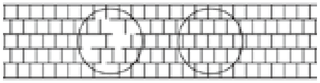


Fig. 13.3 Amorphous regions (left) and crystalline regions (right) of a fibre

Fig. 13.4 Fibre degradation starts from the amorphous regions.

Fibres, man-made or natural, are polymers consisting of small repeating units (monomers). The mechanical properties of polymers depend on the degree of polymerization (DP). Vegetable fibres such as cotton, linen and ramie are cellulosic fibres built up from β -D-glucose units ($C_6H_{12}O_6$)n. Animal fibres, such as wool and silk, are protein fibres made up of amino acids (NH_2CHRCO)n, which have an acidic end, due to the carboxyl groups (－COOH), as well as a basic end (－NH_2). The different properties of amino acids are provided by their side groups, referred to as 'R'. The α -amino acids, which make up a living organism, have the functional group R attached to the carbon, next to the carboxyl functional group.

Polymers contain crystalline and amorphous regions. The crystalline regions are compact and rigid whereas the amorphous regions are segmented and flexible. Swelling due to water absorption as well as the chemical reactions of deterioration commences in the amorphous regions.

Chemical deterioration of fibres can be induced by heat and light radiation, acids and alkalis, chemicals, and biological causes. Fibres may become mechanically weaker due to the decrease in the DP, resulting in loss of tensile strength, elasticity, softness, and hygroscopicity. Sheen and shape can also change due to chemical deterioration.

In acid hydrolysis of cellulose, 1,4 glucoside ether bonds are broken by hydrogen ions (H^+). Water bonds to the carbonium ions (C^+) and hydrogen ions become free and a catalysis effect of hydrolysis sets in. Protein fibres undergo similar catalysis with hydrogen ions and water. Measuring the pH (concentration of hydrogen ions) of the fibre is one way to examine acid hydrolysis.

Measuring the pH is one way to diagnose the condition of the fibre. If the pH of a historic textile is low (more acidic) compared with a new fibre, conservation treatment to remove acid products may be planned.

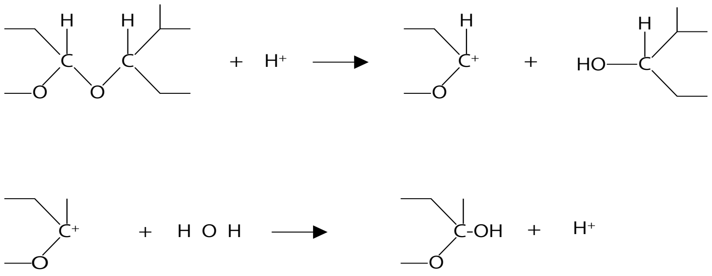
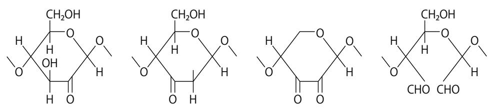
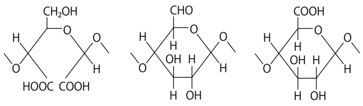


Fig. 13.5 Degradation products of cellulose



(a) ketone on carbon-2 (b) ketone on carbon-3 (c) ketone on carbon-2 and-3 (d) aldehyde on carbon-2 and-3



(e) carboxyl on carbon-2 and-3 (f) aldchyde on carbon-6 (g) carboxyl on carbon-6

Fig. 13.6 Degradation products of cellulose

Fig. 13.7 ① *Kariyasu*, ② Gardenia fruit, ③ Philodendron, ④ Turmeric, ⑤ Safflower, ⑥ Brazil wood, ⑦ Japanese Madder, ⑧ Cochineal, ⑨ Lac, ⑩ Purple root, ⑪ Japanese Indigo

Fig. 13.8 After light fading in stages, day light photography

Fig. 13.9 After light fading in stages, UV photography. Examining dyes with UV light may assist condition assessment of dyes.

Table 13.1 Complementary colour, wavelength and light colour of the visible region[3].

Colour of light	Wave length (nm)	Comlementary colour
Purple	380 - 435	Yellow-green
Blue	435 - 489	Yellow
Green-blue	480 - 490	Orange
Blue-green	490 - 500	Red
Green	500 - 560	Purple-red
Yellow-green	560 - 580	Purple
Yellow	580 – 595	Blue
Orange	595 - 605	Green-blue
Red	605 - 750	Blue-green
Purple-red	750 - 780	Green

6. Dye and degradation pathways (fading)

6.1 Colouring of dyes

Ordinary white light (transparent), coming from the sun or from electric lights, consists of all wavelengths (energy) in the visible region from 380 to 780 nm. When a substance absorbs energy in the visible region, the rest of the visible wavelengths reflect to our eyes, and we perceive colours. For example, in a fabric that we see as "red" the pigment absorbs blue-green light and reflects red light, which is perceived by the eye (Table 13.1). This is the principle of colour development of colouring matter and the human perception of colour.

Among organic substances, there are molecules with a "conjugated system" in which single bonds and two or more double bonds are alternately connected.

$$\sim \mathrm{CH{-}CH{=}CH{-}CH{=}CH{-}CH{=}H{-}CH{=}CH} \sim$$

Polymer with a conjugated system

The colour of molecules depends on the length of their conjugated system, which determines the wavelengths they absorb in the visible region. When molecules are exposed to light or chemicals, they can undergo photodecomposition, photooxidation, or redox reactions that break or modify their bonds. This shortens the conjugated system and changes the colour, making it fade or disappear. Light absorption occurs when the π electron, which is the second double bond, goes from a ground state (a stable state with low energy) to an excited state (an unstable state with high energy). In a conjugated system, the π electrons fly around the entire orbital of the conjugated system to stabilize it, so the absorbed energy is also reduced (the wavelength becomes longer).

Furthermore, when functional groups such as amino groups (—NH) and hydroxyl groups (—OH) are attached to the conjugated system, the absorption wavelength shifts to longer wavelengths. Organic dyes have a long conjugated system and absorb part of the wavelengths in the visible region, so they have colour.

6.2 Fading of dyes

The colour of molecules depends on the length of their conjugated system, which determines the wavelengths they absorb in the visible region. When molecules are exposed to light or chemicals, they can undergo photodecomposition, photooxidation, or redox reactions that break or modify their bonds. This shortens the conjugated system and changes the colour, making it fade or disappear.

The condition assessment of the fading of dyes is done visually. It is useful to create standard dyed fabric references for comparison and as an example of potential fading. The dyed fabrics are exposed to light in intervals and samples of gradual fading are produced. These can be used to compare with historic textiles. This makes it possible to estimate a dye potential to fading, select display light sources, and consider various treatment methods.

Reference

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14 Creasing & Humidification

Fibres are long-chain polymers which have molecules that are compact in the crystalline regions and scarce in the amorphous regions. The strength of a polymer depends on the crystalline region while the amorphous region is responsible for the flexibility and absorbency of low-molecule substances, such as water. A degree of intermolecular force between the polymer chains, such as hydrogen bonds, is necessary to form crystalline regions. Crystalline regions have thermal mobility, and as the temperature rises with applied heat, polymers are sectioned and the mobility of its chain increases. When the temperature is low, the thermal mobility of amorphous regions is also low (glassy stage) and with the rise of temperature, thermal mobility increases (elastic stage). The temperature between these two stages is called Glass Transition Temperature = Tg . The Tg may be lowered by inserting a low-molecule plasticizer, such as water, into the amorphous regions which will make the fibre flexible.

Small water molecules penetrate the amorphous regions of polymers, preventing close contact between the polymers and polymer chains thereby increasing the free volume in the amorphous regions. In this state, the hydrogen bonds between the polymer chains of the fibres are broken allowing for a new alignment of the chains. Hence the creases held in place by these bonds are released. The flexibility of the fibres permits reshaping with applied pressure. New hydrogen bonds form during the drying process which puts the fibres into a new alignment. As a result of this expansion and the chemical reaction within the fibre, the flexibility and softness of the textile are recovered. This is the principle underlying domestic ironing where heat is applied to mobilize crystalline regions, steam (water in vapour form) is inserted into the amorphous regions, pressure is applied to set the polymers in place, and heat quickly reduces the water, allowing new hydrogen bonds to form between the polymers, thus ‘erasing’ creases. Looking chemically at crease removal treatments, one can see how this treatment physically and chemically stresses the fabric.

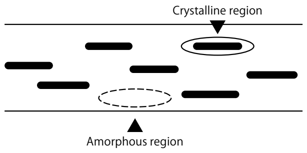

Fig.14.1 Crystalline and amorphous regions of fibres

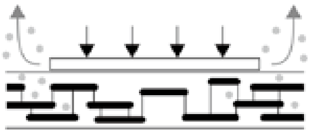

Fig.14.2 New fibres swell as they absorb moisture

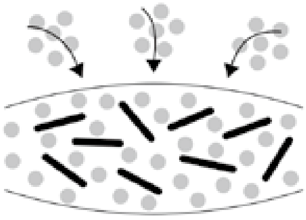

Fig.14.3 When pressure is applied to the fibre during the drying process, the fibre molecules form hydrogen bonds with each other.

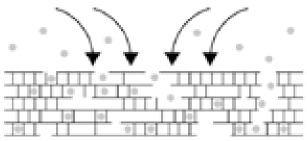

Fig.14.4 Add moisture to the degraded fabric

Fig.14.5 Since the degraded fibres are decomposed, they do not swell and they collapse when water enters.

1. Fibre degradation and treatment

Stiff handle and marked creases are some signs of fibre degradation that are primarily caused by the chemical and physical breakdown in the non-crystalline region of a polymer. As explained above, water is a useful plasticizer which encourages new hydrogen bonds to form which helps to recover the flexibility of a fibre. However, the application of moisture is not always suitable for advanced fibre degradation because polymers are segmented to such an extent that they no longer absorb moisture or reform chemical bonds. In such cases, fibres will simply disintegrate with the application of moisture.

2. Humidification treatment

In textile conservation humidity is used to reshape textiles with methods of open systems and closed systems. Humidification treatments allow the slow introduction of water into the fibre, so that the risk of physical damage, which can be caused in the liquid state of water, is minimized during realigning of fibres. However, there are risks with this treatment since humidification may affect water-sensitive materials. For example, inks may bleed, soils may penetrate deeper into the fibre and stains may spread out[1]

3. Contact humidification (Closed system)

Absorbent materials such as cotton, linen, and blotting paper are dampened with filtered or de-ionised water and layered in combination with dry layers of cotton or non-woven material and then covered with a polyethylene sheet to make a humidification system. The textile may be humidified as necessary from both sides, from either side, overall or partially. During the drying process, the fibres are aligned using weights. The humidity level and humidification speed are controlled by the type and layers of materials.

Gore-Tex® is a semipermeable membrane that has pores 1/2000 of the size of a water droplet (Sympatex® is a similar product). They permit water molecules to pass through from one side of the membrane to the other, and so water vapour is created without the use of heat. Gore-Tex® or a similar membrane is laid against the textile and a wet absorbent layer is placed on top of it. Covering these layers with a polyethylene sheet to hold the moisture nearby, enabling water vapour to reach the fibres quickly and evenly. However, as Gore-Tex® or an equivalent membrane is a costly material, the price may be prohibitive (around $100 per meter).

4. Humidity chamber (Closed system)

A humidity chamber may be made from a plastic container covered with polyethylene sheeting. A moistened material or mist using an ultrasonic humidifier is inserted into the humidity chamber. The textile is then placed inside, and the relative humidity is increased to a predetermined level, maintained, and gradually lowered. A thermometer and a hygrometer are placed in the chamber. This method is suitable when a slow introduction of moisture is required to soften the fibres.

5. Ultrasonic humidifiers (Open system)

Ultrasonic humidifiers divide water into mist, but not into vapour, at room temperature. The mist is used directly on the textile.

6. Steamer (Open system)

Steam is water in its gaseous state (vapour) and is produced by boiling water at 100℃ with the use of a steamer, often a clothes steamer. High humidity and temperature can cause excessive and rapid swelling of fibres, especially when the fibres are degraded and the risk of damage to the textile is high.

Practice1

Crease removal by contact humidification

1 Tools and equipment

Absorbent material (blotting paper, cotton fabric), Gore-Tex®, Sympatex®, non-woven polyester, polyethylene sheet, glass or acrylic sheet, spray, filtered water, polyethylene bag/ sheet.

2. Method

1. Place absorbent material in a polyethylene bag and spray with water.
2. Lay down a polyethylene sheet, then a dry material, the textile, a dry material, and a dampened material. Finally, cover the layer with a polyethylene sheet.
3. Remove the materials when the textile feels damp. Flatten the creases with the hand and place acrylic or glass weights. Change weight positions occasionally to flatten and dry. If creases cannot be removed at one time, repeat the cycle.

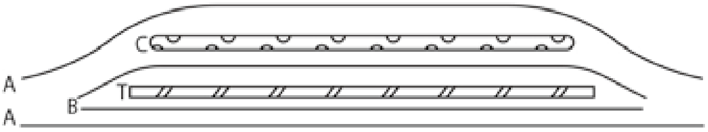

Fig.14.6 Layers of a contact humidification system (see below for notations).

Fig. 14.8 Contact humidification methods using Sympatex® with a moistened absorbent material (cotton) on top.

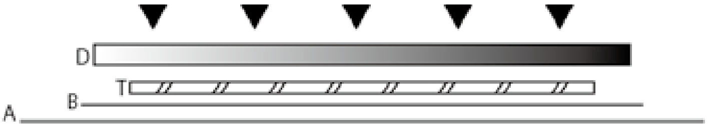

Fig. 14.7 Dry with pressure to flatten the creases after humidification.

D : Acrylic or glass sheet
C : Moist absorbent material (+synthetic non-woven)
T : Textile
B : dry material (+synthetic non-woven)
A : polyethylene sheet

Practice 2 Practice: Crease removal using a humidity chamber


Fig. 14.9 Humidity chamber

1. Tools and equipment

Waterproof container, polyethylene sheet, absorbent material, glass or acrylic sheet, spray, filtered water, polyethylene bag, hygrometer, thermometer, ultrasonic humidifier (if available)

2. Method

1. Make a humidity chamber by covering a container with a polyethylene sheet and placing a hygrometer and a thermometer inside.
2. Insert a wet material or apply humidity using an ultrasonic humidifier.
3. Place the textile inside and gradually raise the humidity, re-shape, and gradually lower the temperature to room level.


Fig. 14.10 Ultrasonic humidifier

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15 Soiling & Cleaning

Dirt on a historic textile often distorts its appearance and accelerates material degradation. It may also cause health problems for the handler. On the other hand, blood stains and food deposits may possess valuable historical evidence for the study of archaeology, anthropology, and ethnography. Cleaning is a non-reversible treatment and if dirt is once removed, it can never be placed back again. For this reason, examining the characteristics and symbolic meanings of dirt is important when considering cleaning treatments.

ICOM Code of Ethics advises in 2.18 Collection Continuity to "pass on (the object) to future generations in as good and safe a condition as practicable." Also, in 2.24 Collection Conservation and Restoration, it states that "the principal goal should be the stabilization of the object or specimen[1]." Hence the main aim of cleaning a historic textile is to stabilize its condition. Recovery of function, appearance and hygiene that is required for cleaning daily wear commodities are not primal goals for a historic textile and must be differentiated. Principles and methods of cleaning historic textiles should be aligned with those of paintings, sculptures, and other museum artefacts.

Until the mid-1950s, cleaning historic textiles was performed as an extension of domestic clothes washing. Scientific research on cleaning historic textiles started around the 1960s. Textile scientist James Rice (Textile Museum, Washington D.C.), defined dirt as "matter out of place" and explained that to remove dirt from a historic textile with minimal damage, scientific knowledge was indispensable[2-3]. Rice gave lectures and endeavoured to educate textile conservators at The Textile Museum. This teaching has formed the basis of present-day textile conservation cleaning.

The development of analytical instruments in the 1980s opened new fields of study. For example, in environmental archaeology, researchers study pollen on unearthed artefacts with a scanning electron microscope to gather information on plant distribution, time and custom of burial etc. What may be considered 'dirt' may hold evidence of research value on a micro-scale. Around the 1990s, with the widespread of preventive conservation, non-interventive conservation methods were devised. In the last 50 years, the treatment methodology for cleaning historic textiles has advanced, and many case studies have been reported/recorded. Compared with practices of the early years, many treatments and chemicals are no longer used.

Removing dirt from a historic textile may lower the risk of material degradation, help recover the appearance and chemically stabilize materials. However as explained above, it may remove historic evidence, which will result in the loss of the academic value of the artifact[4]. Before beginning cleaning, it is necessary to carry out a thorough object and condition examination and evaluate this information. Understanding the extent, amount, content and attachment of dirt, the condition of materials, the historic significance of dirt and damages, material and makeup of the artefact is necessary. The pros and cons of leaving or removing dirt and its chemical and physical effects, in either case, should be assessed. Finally, the decision is made either to leave or to remove dirt. If the decision is to remove the dirt, the methodology should be well-planned.

Points of examination are as below.

- material (fibre, dye, finishing agent, adhesives)
- method of fabrication (fabric, yarn, decoration etc)
- construction
- measurement
- physical damage
- type of dirt and method of attachment
- research the value of damage, dirt, and the decision of removal
- material, fabrication, and methods of cleaning
- cleaning facility and tools

1. Classification of dirt and type of attachment

Dirt on historic textiles may be classified according to its source, characteristic, attachment, harmfulness, and methods of removal[5].

2. Sources of dirt

These are some examples of sources of dirt:

- Dirt deposited during use: fat, food, cosmetics.
- Dirt deposited during burial: earth, sand, salt.
- Dirt deposited during use and storage: air born dust, soil, mould, insect debris, and soot.

3. Harmfulness of dirt

Dirt, if left in place, will penetrate deeply into the fibre causing staining, molecule disconnection and abrasion. It may become a source of nourishment for moulds and microorganisms and disfigure the appearance of the textile. Dirt may cause an allergic reaction in the handler and may lead to health problems.

4. Attachment of dirt

The attachment of dirt can be classified into four categories: physical attachment, molecular attachment, attachment by static electricity and chemical bonds.

4.1 Physical (mechanical) attachment (Figure 15.1)

Dirt with a relatively large size particle may be attached in between weaves of the fabric.

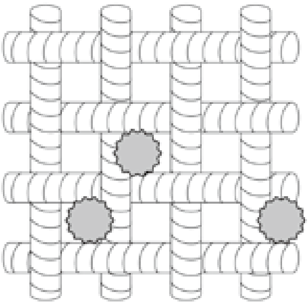

Fig. 15.1 Attraction of dirt

4.2 Dirt which is attached by molecular force

Dirt and fibre may be attracted by molecular forces (van der Waals force), hydrophilic (water-liking) and hydrophobic (oil-liking) properties, which both dirt and fibre possess relative to their attraction. For example, polyester is a hydrophobic fibre that repels water but attracts oils and soot. Cotton is a hydrophilic fibre and attracts water-soluble dirt.

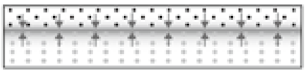

Fig. 15.2 Attraction by static electricity

4.3 Adhesion caused by static electricity (Figure 15.2)

Dirt and fibre may be attracted by electrostatic charge.

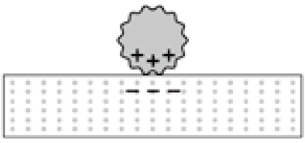

Fig. 15.3 Attraction by chemical bonding

4.4 Adhesion caused by chemical bonding(Figure 15.3)

Dirt and fibre may be chemically bonded at the molecular level.

5.Nature of dirt

Dirt and fibre may be classified into three categories depending on their nature: solid dirt, hydrophilic dirt, and hydrophobic dirt.

5.1 Solid dirt

Solid dirt is material that does not dissolve in water or organic solvents (mud, rust, calcium, calcium carbonate, carbon black etc.). Some hydrophilic dirt wets easily on the surface but others repel moisture. There are particle types of dirt (e.g., sand and fibre) and those forming a large mass (e.g., lumps of mud).

5.2 Hydrophilic (water-liking) dirt

Aqueous dirt may be classified into readily soluble dirt and insoluble dirt. Salt and sugar in food are readily soluble in water, but stains (colourants) and degenerated protein are insoluble.

5.3 Hydrophobic (oil-liking, lipophilic) dirt

Oily dirt may be grouped into fatty acids with strong polarity (e.g., sebum), animal and plant-based oils with medium polarity (e.g., lard, vegetable oils, butter) and mineral oils (petroleum, machine oil) with no polarity. These dissolve in organic solvents but do not mix with water.

6. Classification of dirt according to its removal

The chemical property of dirt and its adhesion influences which removal methods are possible. Removing dirt may be classified into three groups: separation, dissolution, and decomposition.

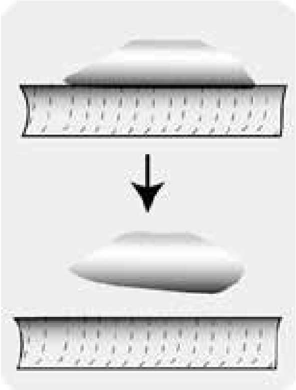

Fig.15.4 Separation

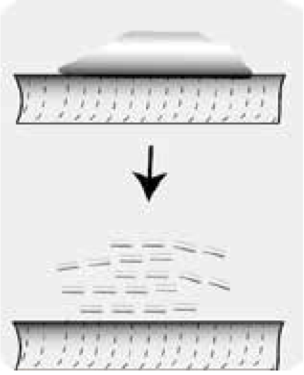

Fig.15.5 Dissolution

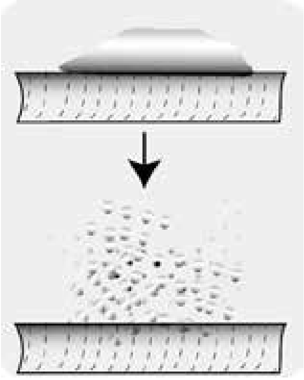

Fig.15.6 Decomposition

6.1 Removal by separation (Figure 15.4)

Particulate soils may be mechanically separated from the fabric but those embedded within the fibre or deposited on a large mass are difficult to separate. Iron rust itself is a particulate soil but when bonded with fibres, it becomes inseparable without decomposition cleaning.

6.2 Removal by dissolution (Figure 15.5)

Dirt may be dissolved in a solvent (water, organic solvent) which breaks up the molecule crystals and disperses them. A surfactant with a hydrophilic and a hydrophobic (lipophilic) nature may aid dispersion when added to a solvent. In general terms 'wet cleaning' uses water and 'dry cleaning' uses organic solvents. The polar nature of water penetrates and wets the fibre, but organic solvents do not. In the conservation of paintings and paper, the term 'dry cleaning' is synonymous with mechanical surface cleaning. To avoid confusion, cleaning using organic solvents is called 'solvent cleaning' in textile conservation.

6.3 Removal by decomposition (Figure 15.6)

Dirt may be dissolved by breaking up the molecules through the use of enzymes, reduction agents, acids, and bases. For example, insoluble stains may be bleached (oxidized or reduced), and degraded protein and starch may be decomposed with enzymes. Hydrophilic particulate soil, such as iron rust, may be decomposed with reduction and chelating (sequestering) agents.

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16 Surface Cleaning

Surface cleaning is the most common method for cleaning historic textiles[1]. Since physically attached soil can be removed through mechanical action, in many cases, textiles can be made ready for display by surface cleaning alone. Methods for surface cleaning involve using a white, soft brush or a soft cloth to remove the surface soil. When using a brush, the soil will disperse so it is necessary to use a vacuum cleaner to suck up the soil to prevent it from redepositing on the object. To prevent the actual textile from being sucked in and damaged by the vacuum cleaner, a net should be placed over the nozzle to lower the vacuum cleaner's suction power. The use of vacuum cleaners with a voltage controller to adjust the suction power, and with a HEPA (High-Efficiency Particulate Air Filter, catches particles up to 0.3 μ m) or ULPA (catches particles below 0.3 μ m) filter to block fungus spores, is highly recommended. Carpets and tapestries which are in good condition can be vacuum cleaned by placing a net over their surface. Silk or ultra-fine synthetic fibre cloth may also be used to remove physically attached soil from textiles which are in good condition. Soil from soot will disperse when a brush is used so it is more effective to remove micro soils using a cloth in a light tapping motion, to reduce its dispersal. It is advisable to remove surface soiling before commencing wet cleaning.


Fig. 16.1 HEPA filter vacuum cleaner, bag, nano-fibre wiping cloth, soft brush, latex sponges


Fig. 16.2 Cleaning mould-infested artefacts in a tent wearing personal protective clothing.


Fig. 16.3 Cleaning the artefact with 80-100% ethanol sprayed onto a wiping cloth.

Ultra-fine microfibre cloths are also effective in removing fine dirt that is physically attached. This is a polyester/nylon blend cloth commonly sold as an eyeglass wipe. The fibre has a function to process countless gaps called micro pockets in ultra-fibre with a diameter of about 2 μ m, and to wipe off oil film and dirt. In particular, soot and other stains can be dispersed with a brush, so they can be removed by lightly tapping with a microfibre cloth. It is desirable to always clean the surface before washing to remove any physical soil between the fabric weaves.

*High Efficiency Particulate Air Filter removes 99.7% of 0.3 μ m particles, Ultra Low Penetration AIr Filter removes 99.99% of 0.152 μ m particles .

1. Cleaning mould infested artifacts

Natural fibres such as cotton, silk, and leather are susceptible to mould attack. Dirt or food deposits are a source of nutrition. Mould is a dangerous type of dirt which may cause allergies and cancer. Anoxia treatment or carbon dioxide treatment are options for mould deactivation. Below is a guideline for cleaning mould-infested artefacts. 76.9-81.4% alcohol in distilled water has a disinfectant property against germs. Alcohols dehydrate germs, eliminating their properties. It is useful to spay alcohol in the air and wipe hands and surfaces when handling mould-infested artefacts.

Mould tends to grow on natural fibres such as cotton, silk, and leather, and dirt and food spills may become a source of nutrition. Mould is a dangerous pollutant that causes breathing problems, inflammation of the skin and mucous membranes, and cancer. After discovering mouldy textiles, do not touch them immediately, and protect your body first. Next, identify the cause of mould growth and reduce the humidity to 60% or less to suppress the growth of mould. When alcohol comes into contact with bacteria, it penetrates cell membranes, causing dehydration, altering, and weakening them. Therefore, it is effective to spray disinfectant ethanol mixed with purified water so that the concentration of ethanol is about 76.9 to 81.4% to kill airborne bacteria and disinfect hands and peripheral equipment. Anti-mould measures include anoxic treatment and carbon dioxide treatment. Here is a procedure for cleaning mouldy textiles[2-5].

① Wear personal protective equipment (PPE)

Wear a mask with a particulate filter from the N series (N for not resistant to oil such as N95, N100 or HEPA, ULPA filter), tight-fitting goggles, disposable vinyl (PVC), or nitrile gloves, disposable coveralls, hair, and shoe covers. Protective clothing should be removed on site and not worn outside the contaminated area.

② Isolate the mould-infested artefact.

Place the object in a thick plastic bag (6 mls, 15 microns) and remove it from the area. If the object is large, place a plastic sheet over it to isolate it from the rest of the collection.

③ Deactivating mould by reducing the humidity to below 50%.

An immediate response to mould infestation is to reduce the RH below 60% and air dry the artefact. Lowering the temperature below 15 ℃ will also help slow or stop the growth. A dehumidifier and an air cleaner fitted with a HEPA filter are recommended.

④ Set up an area to clean the artefact.

Clean mould-infested artefacts inside a fume hood. If this is not available, cleaning the item outdoors is an option. If the object must be treated indoors, and there is no fume hood, make a tent out of a thick plastic sheet and seal it well.

⑤ Cleaning the artefact.

Close vacuuming is one of the most effective ways to remove mould growth and reduce the number of mould spores. Brush the mould towards the vacuum nozzle. Systematically go over the object at least twice. Alcohol wiping and wet cleaning are further options.

⑥ Cleaning and disinfecting tools after work.

After cleaning, wipe the work surfaces and tools with disinfectant alcohol using a disposable cloth. Wash tools and equipment with detergent. These items should be disinfected in 0.5 % sodium hypochlorite bleach (household beach) in water for 15-20 minutes. When discarding items, place them in a thick plastic bag or two layers of thin plastic bags. Seal and discard the bags in an outdoor garbage container.

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17 Solvents & Solubility

In the conservation and restoration of textiles, solvents are used in a variety of situations, including removing soiling, dissolving adhesives and other conservation materials, and dissolving or extracting materials for analysis. Following are definitions of some of the key terminology around solvents.

1. Terminology

① Solute

The substance that is dissolved in a solvent. Examples include ionic crystal materials like salts and materials composed of molecules like pigments.

② Solvent

A liquid that dissolves a solute. These can be broadly divided into polar solvents, such as water and nonpolar solvents, such as oils.

③ Solution

The substance resulting from dissolving a solute into a solvent.

④ Dissolution/Dissolving

The process of mixing and diffusing a material so it becomes uniform, (a solute combined with a solvent resulting in a solution).

Table 17.1 Summary of solvent based cleaning in textile conservation

Type	Solvent	Example of chemicals	Target
Water based solvents	Water	De-ionized water Water by reverse-osmosis Filtered water	Aqueous-based soils, particle soils.
	Water & surfactant	Anionic surfactant Non-ionic surfactant	Aqueous-based soils, oil-based soils, particle soils.
	Acidic solvent	Acetic acid	Metal salts (calcium, iron oxide).
	Alkaline solvent	Ammonium salts	Protein, oils and fats.
	Oxidizing agent (bleaching)	Hydrogen peroxide Sodium perborate	Dyes
	Reducing agent (bleaching)	Sodium borohydride Oxalic acid	Dyes Iron oxide.
	Exogenous enzyme	α -amylase Protease	Starch Protein
Organic solvents	Strong polarity	Ethanol	Natural oils, fats and resins.
	Medium polarity	Acetone	Petroleum-based oils, fats, and synthetic resins.
	Limited or no polarity	Mineral Spirit	Petroleum-based oils, fats, natural rubber and synthetic resins

Fig. 17.1 Solvent dispenser and ethanol in a reagent bottle.

2. Safe handling of solvents

When inhaled or in contact with skin, even in trace amounts, many solvents irritate the eyes, nose, other mucous membranes, and respiratory organs. Some solvents are also known as suspected carcinogens. Chemical substances are assigned identification numbers known as Chemical Abstracts Service Registry Numbers (CAS RN®). Chemicals can be investigated by researching these numbers. The body/group responsible for registering chemicals, determining risks, and assigning safety instructions for each chemical varies with each country. Chemicals, and their Safety Data Sheets (SDS), are obtained from speciality chemical suppliers.

When choosing solvents, it is important to consider the effects on health and the environment. Prioritize the selection of safe solvents, and do not use solvents that you cannot safely handle yourself. Refer to the Safety Data Sheet (SDS) for each chemical before handling solvents, to ensure safe procedures are followed. Always wear personal protective equipment (PPE) including a laboratory coat, safety goggles, and nitrile gloves. Depending on the organic solvent, wear a mask equipped with a special-purpose filter to prevent inhalation. When handling organic solvents, always work under a fume hood or use ventilation equipment. If these are not available, ventilate the inside of the room by opening windows or work outside where there is free-flowing air. If ventilation and PPE are not possible, there are limitations on which solvents can be used.

Distil or gather a small amount of solvent into a special-purpose bottle. The bottle should be designed so that evapouration is limited, and the liquid does not leak out even if the bottle tips over. (Figure17.1) Use the tip of a cotton swab to apply the solvent to the material needing to be dissolved (e.g., soiling). Some substances may swell due to the slight permeation of the solvent into the dissolved substance. In some cases, this may cause clumps of material to break away.

If soiling has permeated into the fibres, dissolution of the soiling can be tested using the following method: Lay blotting paper (or cloth) under the textile. Take up the solvent with a cotton swab. Select an unobtrusive spot and gently roll the swab on the soiled area. Absorb the dissolved soiling with blotting paper (or cloth). Table 17.1 describes the main solvents used in the field of textile conservation.

3. Factors that determine the dissolution of the solute

To achieve dissolution, it is necessary to combine a solute and solvent with similar polarity. The following factors need to be considered:

- Chemical composition of the solute
- Polarity of solute
- Molecular weight of solute
- Temperature

Two key points for understanding dissolution

- Dissolving occurs when the molecular structure is similar
- Whether there is polarity in the molecular structure

Two principles are crucial for understanding the dissolution of substances. The first factor is that dissolving occurs when the molecular structures of the substances are similar. The second factor is whether the molecular structure has polarity. There is an expression that "like dissolves like." Water-based substances dissolve easily in water, and oil-based substances dissolve easily in oil.

3.1 Dissolution occurs when there is a similar molecular structure

To understand why dissolution occurs when there is a similar molecular structure it is helpful to consider the example of salt dissolving in water.

The chemical formula of water is H_2O. The hydrogen ions H^+ and oxygen ion O^{2-} are joined by covalent bonds. In a covalent bond, the partial negative charge on the oxygen atom in the water are bonded by mutually contributing and sharing valence electrons. (Figure 17.2)

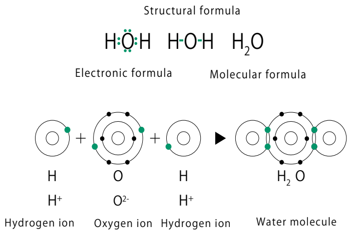


Fig.17.2 Electronic formula, structural formula, molecular formula of water.

H_2O	→	H^+	+	OH^-
water		hydrogen ion		hydroxyl ion
$NaCl$	→	Na^+	+	Cl^-
sodium chloride (salt)		sodium iron		chloride ion

The chemical formula for salt is NaCl (sodium chloride). Salt is an ionic crystal material in which Na^+ and Cl^- are bonded as positive and negative ions. It forms a crumbly cubical crystal. If salt is added to water, the water encloses the salt. This state is called "hydration." The negative charge of the oxygen atom O^- in the water molecule is attracted to the positive charge of the sodium ion (Na^+). Also, the positive charge of the hydrogen atom H^+ in the water molecule attracts the chloride ion C^-. The ionic crystals of salt are broken down and separated into sodium ions Na+ and chloride ions Cl^-. These diffuse through the water, enabling the salt to dissolve in the water*. (Figure 17.3) The structure of the water molecule is bent, and oxygen (O) has a slight negative (δ^-) charge, while hydrogen (H) has a slight (δ^+) charge. Therefore, if there is a material attracted to charge in the water, the water bonds with it, resulting in hydration and dissolution. A substance containing both positive and negative charges is called a polar substance. (Figure 17.4) When a solute and solvent have the same structure and are mixed, the positive and negative ions of the molecules are attracted to each other. The molecules are broken down and diffuse, resulting in dissolution.

*Substances which ionize into positive and negative ions in this way are called "electrolytes." If particles are numerous, it is hard for them to disperse in water and undissolved crystals form. This state is called "saturation."

3.2 Polarity in molecule structure

To understand what it means for a molecular structure to have polarity, it is helpful to consider ethanol and hexane as examples.

The molecular formula of ethanol is C_2H_6O. In the structural formula, a hydroxyl group (—OH) is attached to an ethane group (—C_2H_5) made up of five hydrogen (H) atoms bonded to two carbon (C) atoms. The ethane group is a hydrocarbon (oil) that is hydrophobic (i.e., it repels water) and is not hydrated. A hydroxyl group has a polarity, with oxygen charged negatively ($O^{\delta -}$) and hydrogen ($H^{\delta +}$) charged positively. Therefore, ethanol has both an oil part, as well as a functional group that dissolves in water, so its molecular structure associates with water. (Figure 17.5)

In this way, substances with hydrophobic hydrocarbon groups, that also have hydrophilic groups, such as hydroxyl groups (—OH), carboxyl groups (—COOH), sulphur groups (—SO_3H), or amino groups (—NH_2), have polarity. They are polar

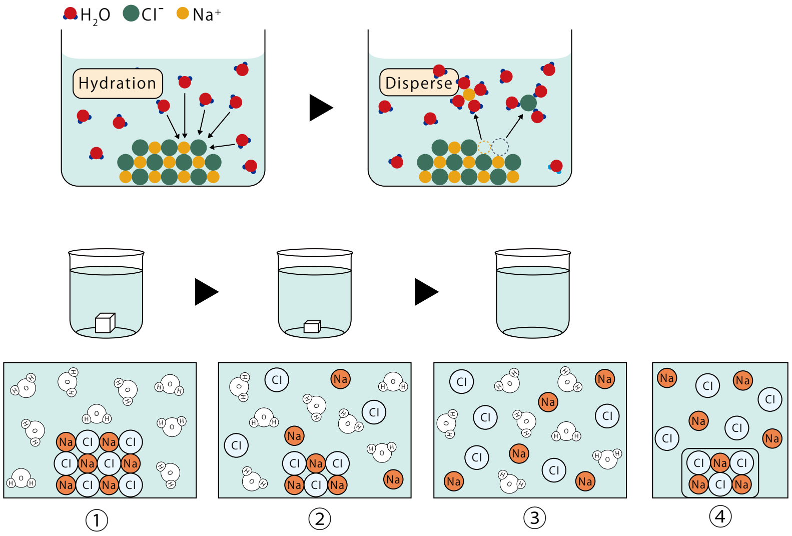


Fig. 17.3 Hydration and diffusion of salt ① Solute: salt, ② Solvent: water, dissolution: dissolved salt, ③Solution: saline solution, ④ Saturation: insoluble salt mixture

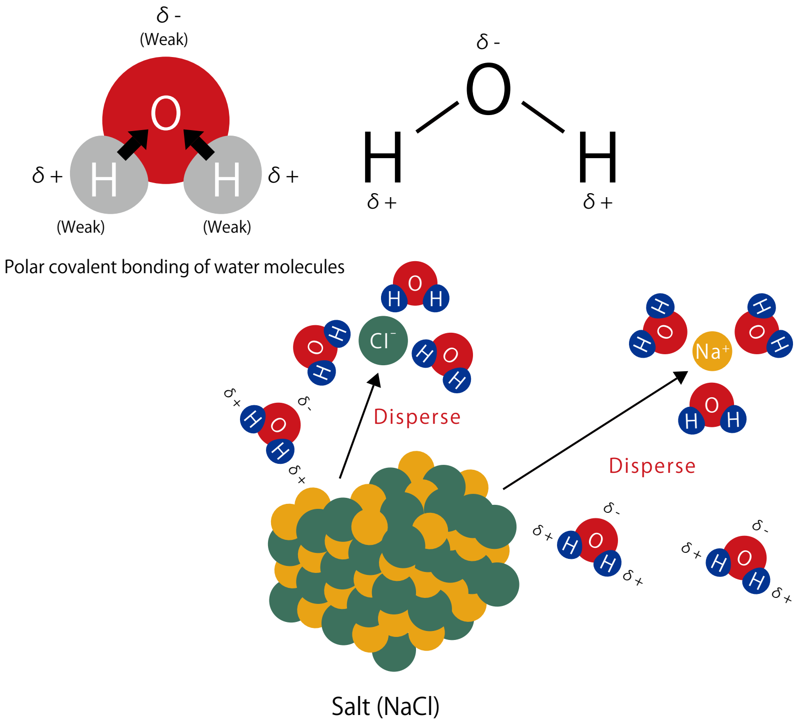


Fig. 17.4 Polarity and covalent bonding of water molecules (top)
Salt (NaCl) separates into Na^+ and Cl- depending on the polarity of water molecules and disperses and dissolves in water.

solvents that dissolve in water. In general, solvents with hydrocarbon groups are called organic solvents.

The molecular formula of hexane is C_6H_{14}. This is a hydrocarbon in which carbon (C) and hydrogen (H) are bonded together. It has a high molecular weight and no characteristic groups with polarity. On the other hand, 1-hexanol is hexane with a hydroxyl group (—OH) as a functional group. The hydrocarbon group is large, so it is a weakly polar or nonpolar solvent that almost does not dissolve at all in water. (Figure 17.6)

This example illustrates that those substances with similar polarity dissolve with each other. It is possible to check the polarity of a solvent by examining whether the molecular structure of the substance has polar functional groups. The strength of polarity varies depending on the size of the hydrocarbon group, and the type of functional groups.

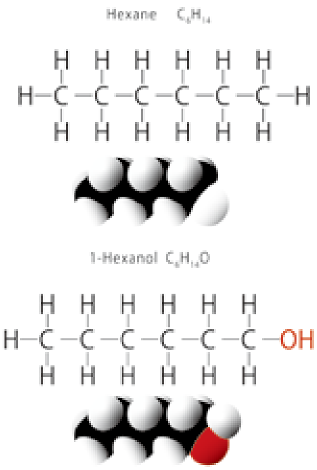


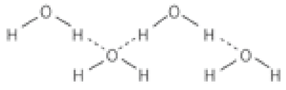
Fig. 17.5 Hexane (non-polar solvent) (top)
Hexanol (weakly polar solvent) (bottom)

4. Three types of solvents based on polarity

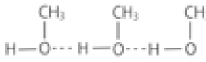
Solvents can be classified into three types based on the strength of their polarity: strong polarity, neutral polarity, and weak polarity/non-polarity. In this section solvents often used in textile conservation will be explained[1].

4.1 High-polarity solvents

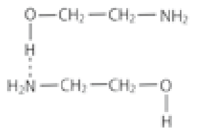
Organic solvents containing water, alcohol, or nitrogen are typical high-polarity solvents. They have hydroxyl groups (—OH) or amino groups (—NH_2) as functional groups in their molecules, and molecules are joined by hydrogen bonds. Hydrogen bonds form between solutes and solvents with the same functional groups, so they scatter, diffuse, and dissolve.



Water



Methanol



1-amino-2-hydroxy-ethane

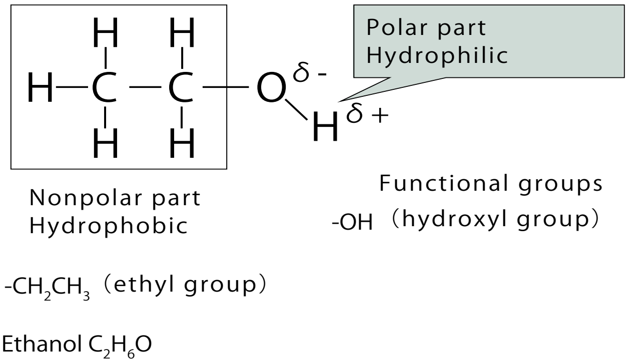


Fig. 17.6 Hydrophobic and hydrophilic groups of ethanol

Table 17.2 Solvent parameters and solvent safety

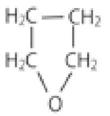
Symbols: ○ = Toxic ◎ = Carcinogenic, effects on foetuses.

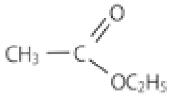
ID	Solvent	Solvent parameters			Flamability	Causticity	Health toxiticy	Environment toxiticy	CAS No.
		① f_d	② f_p	③ f_h					
	Aliphatic hydrocarbon solvents								
A1	White spirit	90	4	6	○	—	○	○	64475-85-0
A3	n-heptane	100	0	0	○	—	○	○	142-82-5
	Aromatic hydrocarbons								
B1	Benzene	78	8	14	○	—	◎	○	71-43-2
B2	Toluene	80	7	13	○	—	◎	—	108-88-3
B3	Xylene	83	5	12	○	—	◎	○	1330-20-7
	Cyclic hydrocarbons								
T2	Turpentine	77	18	5	○	—	○	—	8006-64-2
T3	Cyclohexane	94	2	4					
	Alcohols								
C1	Methanol	30	22	48	○	—	◎	—	67-56-1
C2	Ethanol	36	18	46	○	—	○	—	64-17-5
C3	1-propanol	40	16	44					71-23-8
-	Isopropanol	41	18	41					67-63-0
C4	1-butanol	43	15	42					71-36-3
-	n-pentanol (amyl alcohol)	46	13	41					
C6	Cyclohexanol	50	12	38					
C7	Diacetone alcohol	45	24	31					
D1	Glycerine	25	23	52	—	—	—	—	56-81-5
D2	Ethylene glycol	30	18	52					107-21-1
W	Water (distilled water)	18	28	54	—	—	—	—	7732-18-5
	Ketones								
E1	Acetone	47	32	21	○	—	○	—	67-64-1
E2	Methyl ethyl ketone	53	26	21	○	—	○	—	78-93-3
E3	Methyl isobutyl ketone	582	22	20					108-10-1
E4	Isoamyl methyl ketone	55	28	17					110-12-3
E6	Cyclohexanone	55	28	17					108-94-1
	Esters								
F1	Ethyl acetate	51	18	31	○	—	○	—	141-78-6
F2	Propyl acetate	57	15	28					109-60-4
F3	Butyl acetate	60	13	27					123-86-4
	Ethers								
G1	Methyl cellosolve	39	22	39					109-86-4
G2	Ethyl cellosolve	42	20	39					111-76-2
G3	Butyl cellosolve	42	18	36					111-76-2
G4	Ethylene glycol diethyl ether	48	23	29					112-36-7
G7	Tetrahydrofuran	55	19	26	○	—	○	—	109-99-9
G8	1,4-dioxane	67	7	26					123-91-1
	Chlorine-based solvents								
H1	Dichloromethane	62	26	12					75-09-2
H2	Chloromethane	67	19	14					75-00-3
H3	Trichloroethylene	70	19	11	—	—	◎	○	79-01-6
H5	Chloroform	67	12	21	—	○	◎	○	67-66-3
H6	Carbon tetrachloride	85	2	13					56-23-5
	Nitrogen compounds								
I2	N, N-dimethylformamide	41	32	27	○	○	○	—	68-12-12
	Organic bases								
K1	Ethanolamine	32	29	40					141-43-5
-	Pyridine	56	26	18	○	○	○	○	110-86-1
	Sulphide compounds								
S1	Dimethyl sulfoxide	41	36	23					67-68-5
S2	Carbon disulphide	88	8	4					75-15-0

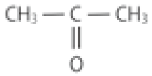
(See reference 1.)

4.2 Neutral-polarity solvents

Neutral solvents include ethers (R–O–R'), carboxylates (R–COO–R'), ketones (R–CO–R'), and organochlorides (covalent bonds with chlorine atoms), and molecules are bound through dipole interaction. Tetrahydrofuran (ether group), ethyl acetate (carboxylate group), acetone (carbonyl group), and trichloroethylene (organic chloride) are typical neutral-polarity solvents. These dissolve solutes with the same functional groups. Examples of solutes dissolved by neutral-polarity solvents are fats (main component: fatty acids C_nH_mCOOH), vegetable oils (main component: fatty acids and glycerine $C_3H_8O_3$), and waxes (main component: higher fatty acid esters).


Tetrahydrofuran


Ethyl acetate


$CH_3-\underset{\underset{O}{\|}}{C}-CH_3$

Acetone

$Cl_2C=CHCl$

Ttrichloroethylene

4.3 Low-polarity/Non-polarity solvents

Weak polarity/non-polarity solvents are long-chain compounds of saturated hydrocarbons (made up only of carbon and hydrogen atoms), with electrons arrayed symmetrically in the same number. However, in some cases, the electron arrangement is a little disorderly, and some compounds are asymmetrical. There are also hydrocarbon solvents which exhibit some polarity. These are primarily solvents that use natural gas and petroleum as their raw material. For example, mineral spirits produced through hydrotreatment of petroleum (also known as white spirits, Stoddard solvent, or dry-cleaning solvent; main component: mixtures of $C_9 - C_{16}$ hydrocarbons) are weak-polarity/non-polarity solvents that can be mixed into water in trace amounts.


Paraffin

$CH_3-CH_2-CH=CH-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$

Components contained in mineral spirits dec-3-ene

Table 17.3 Soiling often found on textiles and solvents used to dissolve soiling

Symbols used are the same as Table 17.2.

Substance	Solvents which dissolve the substance	Solvents which partially dissolve the substance
Linseed oil	A1, B1,H5, E2	
Dried linseed oil	pyridine	C1, C2
Gum arabic	C1	
Dammar	A1, B1, B2, B3	E1, E2, C1, C2
Shellac	C1, C2	E2
Bees wax	H5	B1, B2, B3,T2
Paraffin wax		H5, E1
Natural rubber (latex, polyisoprene)	A1, B1, B2, B3, G7	E2
Chlorinated rubber	B2, B3, G7, F1	
Methyl cellulose	H5, H3, W	
Ethyl cellulose	B1, B2, B3, H5, F1, C1, C2	E2
Hydroxypropyl cellulose	G7, H5, I2, pyridine, W	E1
Cellulose nitrate	G7, F1, E2, C1, I2, pyridine	
Polyvinyl acetate	B1, B2, C1, E2, F1, G7, H3, H5, I2, pyridine	B3,C2

(See reference 1.)

5. Fractional parameters and triangle diagram

Fractional parameters and the triangle diagram (Teas charts) are widely used to find solvents suited to a particular purpose in the conservation and restoration of cultural properties[2]. At first glance, these tables seem difficult or complex to interpret, but once the essential principles are understood, these are convenient tools when considering the removal of soiling and the dissolution of conservation materials.

5.1 Graph composition

For fractional parameters and the triangle diagram, solubility values are indicated in the chart-based Hansen solubility parameters, which use variables to set three intermolecular forces pertaining to substance solubility: Dispersion (Van der Waals forces), Polarity (dipolar forces), and Hydrogen bonds[2].

The coordinate axes of the chart are Dispersion (fd), Polarity (fp), and Hydrogen bonds (fh). The bottom side of the graph axes is Dispersion, the right side is Polarity, and the left side is Hydrogen bonding. The solvent parameter is calculated so that, when cohesive energy is added, that is equal to 100, and the ratios reflect the division into the three forces. For graph values, auxiliary lines are drawn so Dispersion runs from the bottom side, slanting to the upper right, Polarity runs horizontally, and Hydrogen bonds run slanting to the lower right. A point is plotted where the three lines intersect.

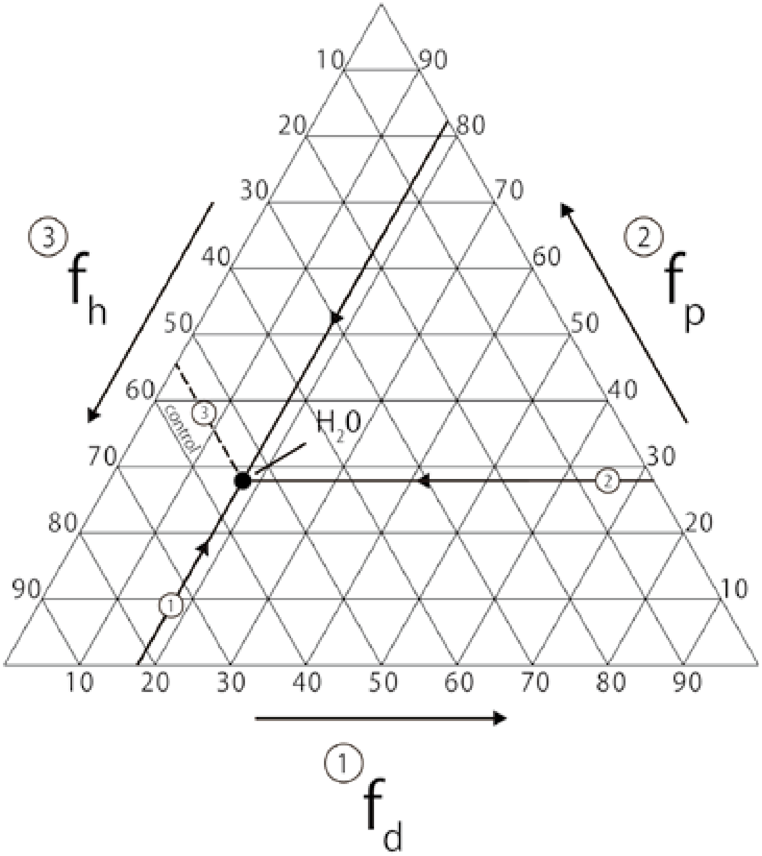


Fig.17.7 Location of water on the triangle diagram.

Dispersion (Van der Waals forces)	(fd)
Polarity (dipolar forces)	(fp)
Hydrogen bonds	(fh)

Cohesive energy density (100 %)= fd + fp + fh

Using water as an example, the fractional parameters are: Dispersion (fd) 18%, Polarity (fp) 28%, and Hydrogen bonding (fh) 54%, so the forces add up to 100%. When the three values are plotted on the triangular graph, the position of water (W) is indicated. (Figure 17.7) In this way, the triangle diagram indicates the solubility values of substances on a graph and this aids in thinking about dissolving problems and solutions. The graph is widely used in the field of conservation due to its ability to visualize solubility.

Dispersion (Van der Waals forces)	(fd)	18%
Polarity (dipolar forces)	(fp)	28 %
Hydrogen bond	(fh)	54 %
	(Total)	100%

5.2 Solubility values of solvents on the triangle diagram

Table 17.6 lists parameters for solvents used in the conservation and restoration of textiles. In Figure 17.8, the polar solvents methanol (C1) and ethanol (C2) are positioned close to water (W) in the Teas chart. The non-polar solvents chloroform (H5), benzene (B1), toluene (B2), and xylene (B3) are gathered on the right edge of the graph, and neutral-polarity solvents are seen around the centre of the graph.

5.3 Dissolution range of various solutes on the triangle diagram

Of the various solutes, the triangle diagram (Figure 17.9) shows the dissolution range for A. Proteins and polysaccharides, B. Fats and oils, C. Waxes, D. Resins, and E. Drying oils. Table 17.3 show types of soiling frequently seen on textiles and solvents for dissolving them. By overlaying the ranges of the solvent and solute, it is easy to find a solvent suited to the substance to be dissolved.

5.4 Using the Teas chart

The Teas chart is used when searching for a solvent to dissolve a solute and to determine the composition of the solute through a dissolution test. For example, if you want to remove partial soiling attached to a textile, search for a solvent using the following procedure.

① Visually examine the components of the solute (soiling) and predict the solvent.
② Find a solvent in the dissolution range of the solute.
③ Perform a dissolution test. Collect a small amount of sample, place it in a test tube, drip in the solvent, and investigate solubility.
④ If the sample dissolves, it is highly likely to be the predicted component, and it is evident that the solvent is effective.
⑤ Connect plotted positions for two solvents with a line. Use this line to infer the mixture ratio of a solution suitable for dissolving the solute. Test solution ratios.

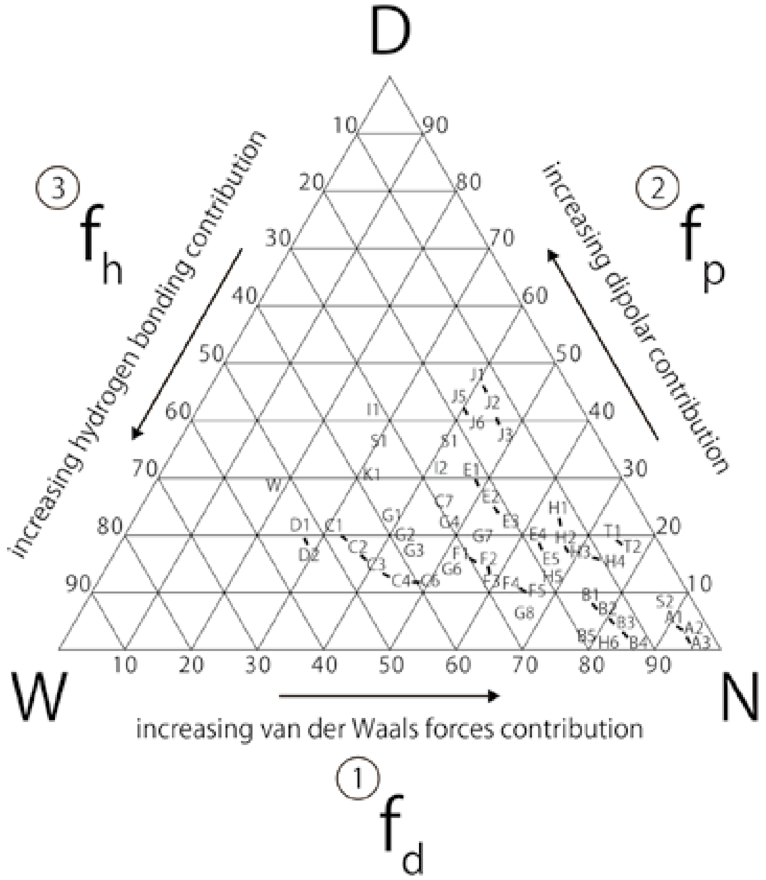


Fig.17.8 Location of solvents on the triangle diagam (see Table 17.2 for the materials and their ID).

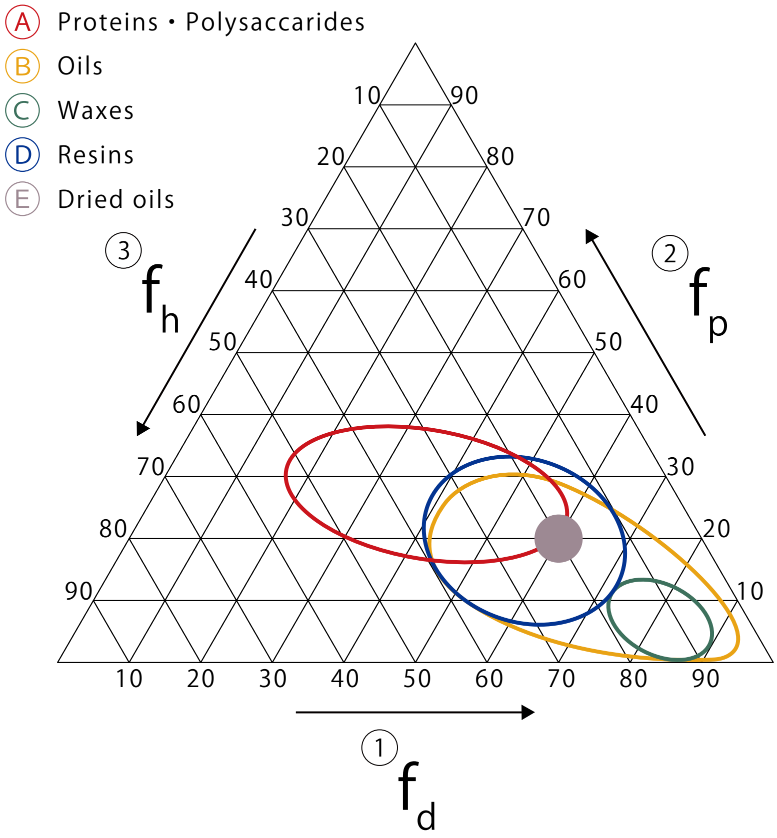


Fig.17.9 Triangle diagram showing the solubility areas of materials.

With historic textiles, there are cases where various materials are complexly bound with the solute (e.g., soiling). Due to the passage of time and the conservation environment, dissolving cannot be easily undertaken on these items. There are also cases where, even if a solvent suitable for dissolving the solute is found, that solvent also influences other materials. For example, even if a solvent is found that dissolves the soiling, it may be impossible to use if it looks like dye pigments will also dissolve. Solvents not only irritate skin and mucous membranes, but some are also highly toxic to respiratory organs, carcinogenic, or have effects on developing foetuses. When choosing solvents, it is important to also consider the effects on health and the environment and prioritize the selection of safe solvents.

Practice 1 Using the triangle diagram

The following are typical solvents used in the conservation and restoration of textiles. Plot on the triangle diagram by referring to the solvent parameters (Table 17.2).

- High-polarity solvents: ① Water, ② Ethanol, ③ Methanol, ④ Ethyl acetate
- Neutral-polarity solvents: ⑤ Acetone, ⑥ N,N-dimethylformamide, ⑦ Methyl ethyl ketone
- Low-polarity/non-polarity solvents: ⑧ Mineral spirits

1. Solvent candidates for dissolving an unknown sample

Observe a sample of the unknown solute you wish to dissolve and predict what it is. Next, draw a line on the graph around the dissolution range of the sample. Propose candidate solvents to dissolve the unknown sample.

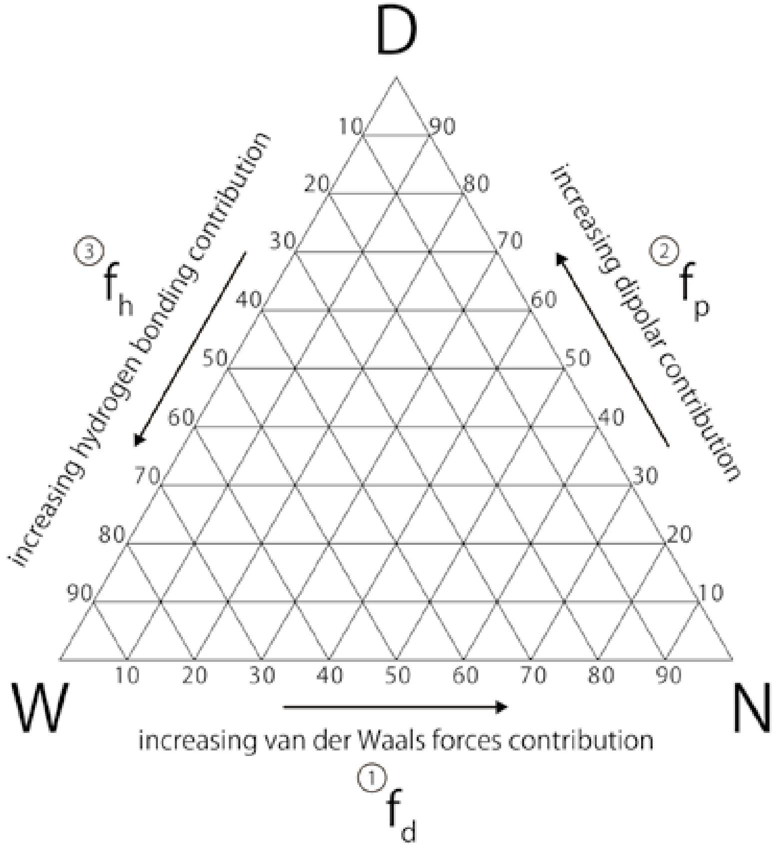


Fig. 17.10 Teas chart/ triangle diagrams present the fractional solubility parameters of solvents.

References

1. Ágnes Tímár-Balázsy and Dinah Eastop. 1998. Solvents and solubility, *Chemical Principles of Textile Conservation*, pp. 163-174. London: Butterworth-Heinemann. Table 1 is taken from Table 8.1 on p. 167, and Table 2 is taken from Table 8.4 on p. 171.

18 Water, Acids & Bases

Water is used in various tasks in textile conservation, including dyeing, washing, and wetting/forming, and as a material for conservation and restoration measures. The chemical formula of water is H_2O. It is a solvent with strong polarity and high/strong dissolving power. Due to this property, various substances are already dissolved in natural water. To determine the quality of tap water supplied to a museum or conservation laboratory, ask the local water authority to undertake an investigation, or conduct water analysis yourself. In this section, water quality and acid and basic reagents often used in textile conservation will be explained[1].

1. Water and water quality

When conducting water analysis, investigate hardness (calcium and magnesium ions), iron ions and other heavy metal salts, degree of acidity (pH), and level of agricultural chemicals. It is particularly important to measure water hardness (mineral composition). If water hardness is high, its effects can be curbed by using a surfactant. (Table 18.1) This is because, in high-hardness water, calcium salts react with soap, producing insoluble metallic soap in the water, and its cleansing power declines.

$$\underset{\text{soap}}{\mathrm{2RCOONa}} \quad + \quad \underset{\text{calcium carbonate}}{\mathrm{CaCO_3}} \quad \rightarrow \quad \underset{\text{metal soap}}{\mathrm{(RCOO)_2\,Ca}} \quad + \quad \underset{\text{sodium carbonate}}{\mathrm{NaCO_3}}$$

Therefore, ABS-based (branched-type alkyl benzene sulfonate) and higher alcohol-based surfactants (including hydrophilic groups — OSO and — SO_3 in active groups), which do not react with calcium salts and have outstanding dispersion, are suitable as detergents in regions with hard water.

To understand the purpose of water use, and the effects of water quality on objects, the Canadian Conservation Institute (CCI) have reported on water quality for applications such as washing, enzymes, bleaching, dyeing, and analysis. (Table 18. 2) To obtain the water quality recommended by CCI it is necessary to install

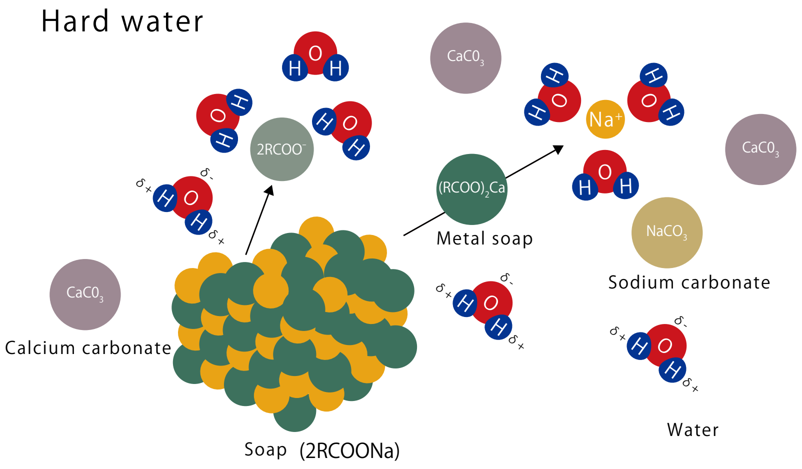


Fig. 18.1 Hard water and soap

Table 18.1 Water hardness

Evaluation	Total hardness $CaC0_3$ (ppm)
Extremely soft water	0-14
Soft water	40-80
Somewhat soft water	80-120
Somewhat hard water	120 – 180
Hard water	180 – 300
Extremely hard water	300 ＜

Table 18.2 Water quality for treating textile and papers, as recommended by the Canadian Conservation Institute[2].

Process or other application	Recommended water quality
Washing or spraying paper or textiles	Ion-exchanged/ Deionized water, fresh water filtered by reverse osmosis membrane, sterilized water filtered by reverse osmosis membrane
pH testing	Freshwater filtered by reverse osmosis membrane
Preparation of aqueous solutions (alkaline buffer solution, etc.)	Freshwater filtered by reverse osmosis membrane
Bleaching	Water filtered by reverse osmosis membrane
Paste or poultice	Freshwater filtered by reverse osmosis membrane
Leafcasting	Ion-exchanged water, water filtered by reverse osmosis membrane, distilled water
Ion analysis (pH, magnesium/ calcium, chlorine, etc.)	Purified water filtered by reverse osmosis membrane
Washing glassware	Distilled water, water filtered by reverse osmosis membrane, purified water filtered by reverse osmosis membrane; after washing with tap water
Washing metal utensils	Water filtered by reverse osmosis membrane; purified water filtered by reverse osmosis membrane
Dyeing	Water filtered by reverse osmosis membrane; purified water filtered by reverse osmosis membrane

filtration equipment in the conservation laboratory. If this installation cost is an issue, it is recommended to purchase filtered water, or, at least, pass tap water through a commercially available drinking water filter to remove general impurities. It is easy to obtain distilled water at pharmacies. Distilled water has strong dissolving power because it does not contain impurities. It may dissolve degraded fibres or colourants, and so is not recommended for use in cleaning or spraying purposes. It is essential to ascertain the characteristics of water, by testing tap water and using the appropriate water for each purpose.

2. Acids and bases in the conservation of textiles

Acidic and basic (alkaline) chemicals are utilized as cleaning agents. For example, acidic table vinegar is used to remove water scaling, and basic sodium carbonate is used to clean dishes and bleach dishcloths. While acids and bases break down soiling, there are cases where they cause changes in the fibres or dyes of textiles. Always keep in mind that both acids and bases are dangerous chemicals for historic textiles. Therefore, in the conservation of textiles, it is crucial to know acid and base characteristics and to use these safely as reagents for conservation measures and material analysis.

2.1 Safe handling

If you touch acidic or basic reagents, even in trace amounts, it may irritate your skin, eyes, or mucous membranes. These reagents may also damage the lungs if inhaled in a volatile form. When handling chemicals, always wear a white laboratory coat, safety goggles, and nitrile gloves to protect your body. Perform work under a ventilation exhaust hood, or indoors after opening windows and ventilating well. Read the chemical handling instructions (MSDS) and be thorough about safety management.

2.2 Degree of solution acidity, basicity; Hydrogen ion concentration index pH

pH is an index of hydrogen ion concentration $[H^+]$ in solution ($pH=-\log[H^+]$). It indicates the degree of acidity or basicity on a scale from pH 0 to 14[3]. The hydrogen ion concentration $[H^+]$ and hydroxide ion concentration $[OH^-]$ of pure water (H_2O) are balanced, and both are 10^{-7} M/l so pH 7 is neutral. If the hydrogen ion concentration $[H^+]$ is higher, the solution is acidic (pH 0-6), and if the hydroxide ion concentration $[OH^-]$ is higher, the solution is basic (alkaline) (pH 8-14). There are anhydrous acids, and basic chemicals in a dry state, but measurement of pH can only occur after ionizing water into hydrogen ions and hydroxide ions. Also, pH does not apply to organic solvents. Measured values vary depending on factors such as the amount of water, temperature, and equipment/materials used (testing paper, reagents, pH measuring equipment).

pH scale: pH 0 acidic < 7 neutral < 14 basic

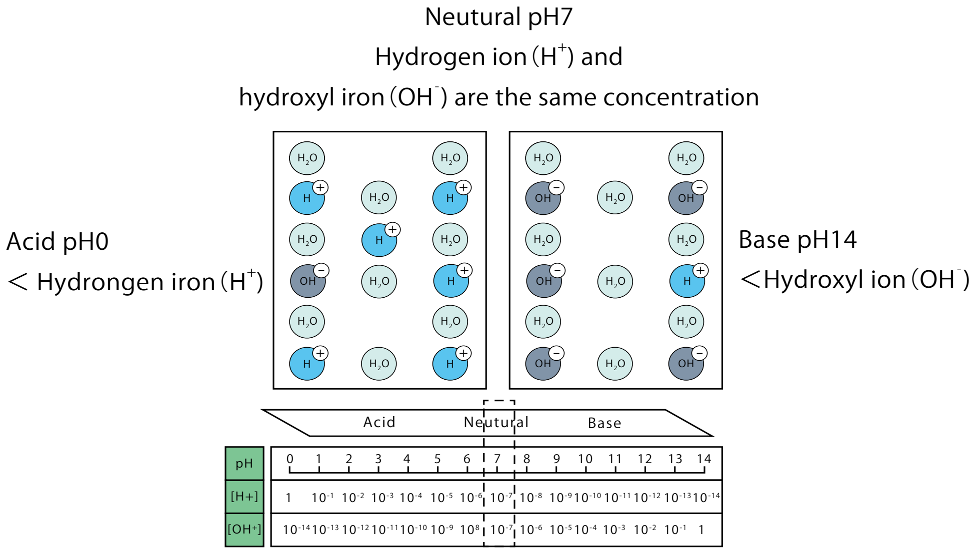


Fig. 18.2 Index of hydronium ion concentration of a pH scale

2.3 pH measurement method

For measuring pH, there are methods using indicator reagents, and methods using electrodes.

2.3.1 pH pens

A pH pen uses, as ink, a pH indicator reagent, where the pigment colour changes depending on acid and base concentration. This is convenient for simple testing of conservation boxes, and conservation papers, but should not be used directly on textiles.

2.3.2 pH indicator strips / Test papers

pH indicator strips also use pH indicator reagents, and they allow the measurement of various pH ranges. If more precise values are not needed, test strips/ indicator paper is broadly applicable over the range of pH 0-14. pH is determined by placing the test paper in the aqueous solution for 1-2 seconds and then comparing the colour change against a colour chart.

2.3.3 pH measuring instruments

These use electrodes to measure the concentration of hydrogen ions (H^+) and hydroxide ions, which have been ionized, in an aqueous solution. Measurement is undertaken by placing the electrodes in the aqueous solution or touching them to the surface of wetted fibres.

3. Acids

Acids produce hydrogen ions (H^+) in an aqueous solution, and these hydrogen ions (H^+) affect other substances. Acids are divided broadly into strong and weak types. The term "strong acids" refers to aqueous solutions in which numerous hydrogen ions are dissociated (i.e., strong electrolytes). "Weak acids," on the other hand, are aqueous solutions in which hydrogen ions are partially dissociated (i.e., weak electrolytes). Substances with carboxyl groups ($-COOH$), like acetic acid, are generally weak acids.

Among acids, there are many reagents with different characteristics. Select the reagent which best suits the intended purpose, such as pH adjustment for dyeing, calcium dissolution, reduction/removal of iron oxide, etc. Acids change the colour of cellulose, proteins, and dyes and some metals may corrode in contact with it. As a general rule for conservation activities, care should be taken to ensure that components with an adverse effect on textiles are not left behind after measures are finished. Therefore, acids with volatility are preferred. Table 18.3 shows the main acids used in the conservation treatment of textiles[4].

When diluting high-concentration acids, always add acid to water, a little at a time while stirring. Never add water to acid as this will produce heat.

Table 18.3 Acidic reagents

Name	Molecular formula	Category	Remarks
Hydrochloric acid CAS No. 7647-01-0	HCl	Strong acid	0.1% concentration: pH 1.6 Dissolves cellulose, protein, discolouration of chemical fibres, and dyes. Separates metallic complex salts, dyes, and fibres in pigment extraction for dye analysis. High volatility.
Sulfuric acid CAS No. 7664-93-9	H_2SO_4	Strong acid	0.1% concentration: pH 0.7 Dissolves protein. Reagent identification for dyes. Non-volatile.
Formic acid CAS No. 64-18-6	$HCOOH$	Strong weak acid	0.1-1.0% concentration: pH 2.7-2.2. Dissolves nylon, cellulose, and acetate. Strongest acid among carboxylic acids. Volatile. Flammable.
Acetic acid Glacial acetic acid (100%) CAS No. 64-19-7	CH_3COOH	Weak acid	1% concentration: pH 2.8, 0.1% concentration: pH 3.3 Glacial acetic acid freezes at 16.6° C. Dissolves acetate, natural resins, vegetable oils, indigo pigment, and a purple pigment. Frequently used acid. Cleaning solvent (dissolves calcium).pH regulator. Fixing of acid dyes (used at 1–4% concentration). Dissolution and colouration identification test for dyes. Volatile.
Oxalic acid CAS No. 144-62-7	$H_2C_2O_4$ (HOOC-COOH)	Strong weak acid	0.1% concentration: pH 1.6, 1% concentration: pH 1.0 Does not dissolve well at low temperatures but does dissolve well at high temperatures. Is not volatile, so forms needle-like crystals when drying occurs. Not used very often in conservation treatment for this reason. General cleaning agent (iron oxide reducing agent). In wet treatment, rinse well. Non-volatile.
Citric acid CAS No. 5949-29-1	$C_6H_8O_7$	Strong weak acid	2% concentration: pH 2.1 General cleaning agent (iron oxide reducing agent). Non-volatile. Forms crystals when dried. In wet treatment, rinse well.
Boric acid CAS No. 10043-35-3	H_3BO_3	Weak acid	1% concentration: pH 5.0 Pesticide, bactericide. Reagent identification for dyes. Non-volatile. Forms crystals when dried. In wet treatment, rinse well. Skin corrosion.

4. Bases (Alkali)

Bases produce hydroxide ions (OH^-) in an aqueous solution leaving behind the hydroxide ions and receive hydrogen ions (H^+) from other molecules[5]. Strong bases are aqueous solutions in which numerous hydroxide ions are dissociated. In weak bases, these are only partially dissociated. Basic chemicals also exist in an anhydrous state (dry solid), and hydroxide ions are produced when they are dissolved in water. Examples include calcium oxide and calcium hydroxide. Ammonia (NH_3) also exhibits basicity by bonding with hydrogen ions (H^+) in an aqueous solution.

Among bases, there are many reagents with different characteristics. Select the reagent which best suits the intended purpose. Bases change proteins and dyes. Strong bases dissolve glass, so caution is necessary when using labware made of glass.

$$\underset{\text{calcium oxide}}{Ca(OH)_2} \rightarrow \underset{\text{calcium iron}}{Ca^{2+}} + \underset{\text{hydroxyl iron}}{2OH^-}$$

Table 18.4 Basic reagents

Name	Molecular formula	Category	Remarks
Sodium hydroxide CAS No. 1310-73-2	$NaOH$	Strong alkali	0.1% concentration: pH 12.3 Dissolves protein and breaks down some chemical fibres and degraded cellulose fibres. Dissolves some dyes. Non-volatile.
Potassium hydroxide CAS No. 1310-58-3	KOH	Strong alkali	0.01% concentration: pH 12 Dissolves protein and breaks down some chemical fibres and degraded cellulose fibres. Dissolves some dyes. Non-volatile.
Calcium hydroxide CAS No. 1305-62-0	$Ca(OH)_2$	Strong alkali	0.05% concentration: pH 13 Neutralization or buffer agent for acidic paper. Calcium sulphate is produced by bonding with sulfuric acid in the acidic paper. Calcium carbonate, insoluble in water, is produced through the bonding of residual alkali with carbon dioxide in the air. Oxidation is inhibited because it stays inside the paper as a buffering agent. Non-volatile.
Ammonium hydroxide (ammonia water) CAS No. 1336-21-6	NH_4OH	Weak alkali	1% concentration: pH 9.1, 0.1% concentration: pH 8.6, 1 M concentration: pH 11.36 pH regulator. Cleaning solvent (dissolves fats and oils.) Reagent identification for dyes. Most frequently used. Volatile. Bitter odour.
Sodium perborate CAS No. 7632-04-4	$NaBO_3$	Weak alkali	1% concentration: pH 10.5 Cleaning agent (bleaching). Non-volatile.

5. Salts

Salts are produced when an acid and alkali are combined. Table salt (sodium chloride) is illustrated below as an example.

Na^+OH^-	+	$H+Cl^-$	→	Na^+Cl^-	+	H_2O
sodium hydroxide （strong base）		hydrochloric acid （strong acid）		sodium chloride （salt）		water

An aqueous solution of a salt, produced from a strong acid and strong alkali, is called a neutral salt, as it has a pH of 7. An alkali salt is produced by a weak acid and a strong base, and the aqueous solution exhibits basicity. An acid salt is produced by a weak base and strong acid, and the aqueous solution is acidic. With a weak acid and weak base, the pH of the aqueous solution is determined by whichever is more prevalent hydrogen ions (H^+) or hydroxide ions (OH^-).

Bases form hydrogen bonds with fats, oils, and resins that have ester bonds (R-COOR-R') and produce soap (alkali salts). Therefore, the fats, oils, and resins are changed into a state that can be dissolved in water and are removed by washing. Acids and bases produce salts, so they are also used as neutralizers[6].

Table 18.5 Various salts

Name	Molecular formula	Category	Remarks
Sodium sulfate CAS No. 7647-01-0	Na_2SO_4	Neutral salt	pH 7 Salt is safe for the human body. Breaks down into crystal water at 32.38° C. This is employed as an auxiliary for preventing irregular colour in dyeing, based on the property whereby solubility declines as the temperature rises. Common names are Mirabilite and Glauber's salt.
Sodium carbonate CAS No. 497-19-8	$NaCO_3$	Alkali salt	1% concentration: pH 12.1, 0.1% concentration: pH 11.2 Damages protein fibres, cellulose fibres, and some chemical fibres. Elutes dye. Common names are soda ash and washing soda.
Sodium bicarbonate （sodium hydrogen carbonate） CAS No. 144-55-8	$NaHCO_3$	Alkali salt	1% concentration: pH 8.3 Weak alkali salt, but it damages materials that react with alkalinity. Dissolves a little in water, dissolves somewhat in ethanol, and is insoluble in methanol. The common name is baking soda.
Sodium metasilicate CAS No. 6834-92-0	Na_2SiO_3	Alkali salt	0.1% concentration: pH 11.4 Damages protein fibres, cellulose fibres, and some chemical fibres. Elutes dye. Stabilizer used for bleaching. Auxiliary that promotes the removal of iron.
Sodium or potassium salt of fatty acids (soap)	RCOOM	Alkali salt	0.2% concentration: pH 10 Sodium is a solid and potassium is a liquid. Chemical formulas differ depending on the raw material. Palm oil, lauric acid（$C_{11}H_{23}COOH$） Beef tallow, stearic acid（$C_{17}H_3COOH$） The common name is soap.

Practice 1 Water quality test

It is important to perform water analysis before undertaking wet cleaning tasks. When washing historic textiles, chlorine has a bleaching action. Iron should be removed with a water-purifying filter, as it is known to colour fibres red. Other metal ions, including zinc and copper, also elute from water pipes causing discolouration when bonding with fibre and dye. When there is a large amount of calcium or magnesium in water its hardness increases, and the action of detergents may be reduced. Distilled water can easily dissolve various substances because it does not contain impurities. It may cause the bleeding of dyes, so is not recommended for washing historic textiles. Contamination in tap water can be removed by passing through a commercially available water purification filter for drinking water.

1. Materials and equipment

Fig. 18.3 Water quality inspection using various test papers.

Chlorine (Cl), zinc (Zn), iron (Fe), copper (Cu), total hardness (TH) measurement test paper (e.g., Johnson Test Papers), pH test paper (pH 0-14), water purification filters (e.g., BRITA® Water filter + Maxtra Cartridge - Ion exchange membrane and activated charcoal), tap water, distilled water, test tubes, thermometer

2. Method

1. Place water in each test tube.
2. Measure temperature and pH.
3. Measure components of water with reagents or test paper.

Practice 2

pH measurement testing of fibres in conservation materials

Measuring the pH of fibres enables the conservator to ascertain the degree of fibre degradation (detecting dissolved oxides). It also serves as an indicator of the degree of acidity of conservation paper, and other storage materials. Measurement of pH is only possible when hydrogen ions and hydroxide ions are dissociated in water. For this reason, to measure pH it is necessary to first wet the area. The following equipment and materials are used to measure the pH of paper or cloth fibres.

1. pH pen

Draw a line with the pen on the test paper and compare the colour with the included indicator.

2. pH test paper

Fig. 18.4 pH test paper

Use a good quality pH test paper that does not stain the fibre with the indicator (Figure 18.4).

① When sampling fibres for measurement

1. Sample a small number of fibres from the specimen.
2. Place 3-4 drops of distilled water in a test tube, add fibres, and shake the test tube.
3. After 1 minute, place the pH test paper in the aqueous solution. Compare the colour with the included indicator and determine the pH value.

Fig. 18.5 A pH meter measures hydrogen ion concentration with an electrode.

② When directly measuring the specimen

1. Wet the measurement point with distilled water.
2. Place pH test paper on the wetted area.
3. Place a weight on top and wait for around 1 minute. Compare the colour with the included indicator and determine the pH value.

3. pH measuring instrument (glass electrode type)

Fig. 18.6 Soak the electrode in the solution and measure the pH.

Calibrate the measuring device with a pH standard solution to prepare it for accurate measurements. Measure the pH value by placing the electrodes in the aqueous solution with sampled fibres or touching them to the surface of wetted fibres.

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19 Surfactants & Wet Cleaning

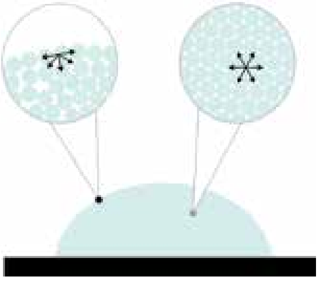


Fig. 19.1 Surface tension of a water droplet

1. Surface tension of liquids

Permeation is necessary for a liquid to dissolve another substance as a solvent. In liquids, the molecules attract each other, and a force acts to minimize surface area. This is called surface (interface) tension. The term "surface" refers to the boundary surface between a gas and a liquid, or between a liquid and a solid. The surface of the water is a boundary between water and air, and one example of surface tension is how water drops and soap bubbles form into spheres. When the surface tension is high, it is hard for a liquid to permeate into another substance. When a drop of liquid is dripped, the contact angle it makes with a surface serves as an indicator of the ease with which the liquid spreads. Water has high surface tension, so water drops are round. The contact angle is 150° or higher, and the liquid does not spread. Temperature affects surface tension. When temperature increases, the movement of molecules becomes more energetic, reducing surface tension, and making it easier for the liquid to spread. Surface tensions of some important liquids are shown in Table 19.1.

To facilitate the permeation of liquid, as a solvent, into a solute, it is necessary to change the energy relationship at the boundary surface. Increasing the temperature is one way to achieve this. Another way is to mix the solvent with a liquid with low surface tension. For example, if ethanol is added to water, the surface tension decreases, and the liquid permeates into fibres more easily. This property is used in the conservation of textiles. Ethanol is mixed with water and used for moistening and cleaning.

Table 19.1 Surface tension of liquids

Liquids	Surface tension (Dyn/ cm, 20 ℃)
Methanol	22.0
Acetone	23.7
Ethanol	22.3
White spirit	25.0
Water	72.8 40℃ 67.55 100℃ 58.84
Acetic acid	27.7
Ammonia water	59.3
Mercury	485

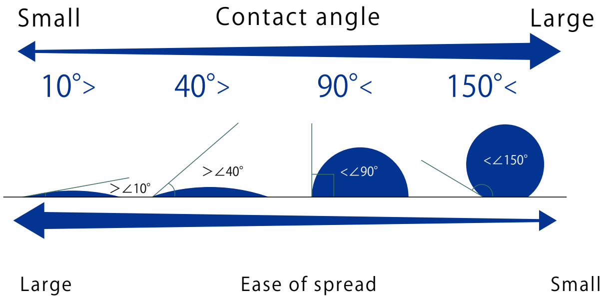


Fig. 19.2 Ease of liquid spreading in relation to the contact angle.

2. Types and properties of surfactants

2.1 Types of surfactants

Surfactant molecules are characterized by having both hydrophilic groups with an affinity for water, and lipophilic groups with an affinity for oil. Also, there are ionic surfactants which dissociate into ions in an aqueous solution, whose hydrophilic groups have ionicity, and non-ionic surfactants which do not dissociate into ions, and that exhibit water solubility. Surfactants can be broadly divided into four types[1] (Table 19.2).

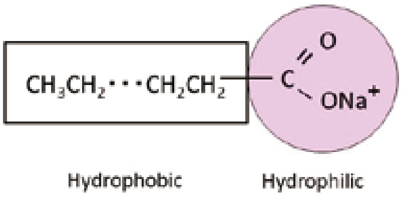
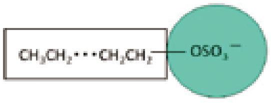
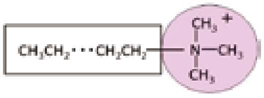
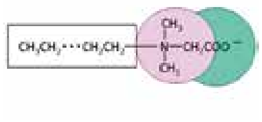


Fig. 19.3 The fatty acid salt of soap is a surfactant, and the molecule has a hydrophobic group and a hydrophilic group, so it has the detergency to disperse oil and water stains.

Table 19.2 Types and primary applications of surfactants

Ionic surfactants	① Anionic (negatively charged)		Clothing detergents Shampoo Body soap
	② Cationic（positively chraged)		Clothing softeners Hair conditioners
	③Amphoteric surfactants (the hydrophilic group is negatively charged in alkaline aqueous solution, and positively charged in acidic aqueous solution)		Shampoo Kitchen detergents
Non-ionic surfactants	④ Non-ionic		Clothing detergents Emulsifiers Dispersants

2.2 Properties of surfactants

2.2.1 Decrease in surface tension

Surfactants have the property of reducing surface tension by acting on the surfaces of liquids and the boundaries between liquids, and between liquids and solids. In terms of mechanisms, when a surfactant is added to water, the molecules align themselves, so the hydrophilic part projects into the water, and the lipophilic part projects into the air. This reduces surface tension, making it easier for the liquid to spread and wet fibres. When the surface tension is reduced, surfactants act as emulsifiers of water and oil, dispersants of oil, water, fine powders, and foaming agents of air and water.

2.2.2 Formation of molecule clusters and micelles

Surfactants have the property of gathering and aligning on an interface (surface). With water in a container, there are two boundary surfaces: water and air, and water and the container. When a surfactant is added to water, it dissolves and disperses, and forces act on the surfactant molecules. A hydrophilic force tries to keep the molecules in the water, and a lipophilic force tries to separate them from the water. In an aqueous solution with low concentration, molecules try to gather at the interface between the water and air, and between water and the container. However, when the concentration is increased and a saturated state is attained, surfactants that cannot acquire an interface can adsorb to attract each other. They form assemblies called micelles, with hydrophilic groups on the outside and hydrophobic groups on the inside. The concentration where micelles form is called the "Critical Micelle Concentration" (CMC). Surfactants have various types of actions due to this property.

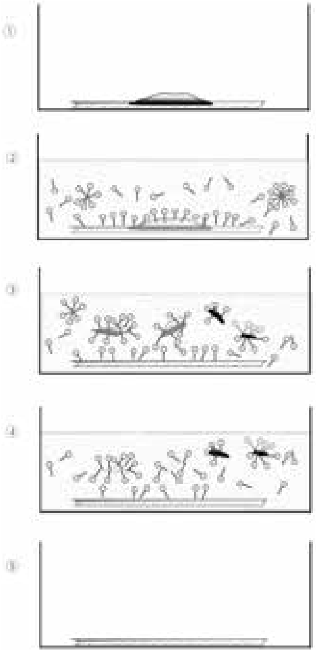


Fig. 19.4 Surfactants exceeding the CMC concentration attach to the surface of the dirt, surrounding it, and float and disperse it.

2.2.3 Mechanisms of surfactants as detergents

When a surfactant exceeds the critical micelle concentration (CMC), it functions as a detergent. If soiled fibres are placed in a washing solution exceeding the CMC, surfactant molecules adsorb to the surface of the soiling, attracting, and lifting it off, and dispersing it in the water. At the same time, surfactant molecules adsorb onto the surface of the fibres, interfering with the reattachment of the soiling. This is the washing mechanism that occurs when a surfactant is added to water[2].

2.2.4 Appropriate temperature

There is an appropriate temperature range for surfactants to function. Ionic surfactants crystallize at low temperatures and do not disperse well in water. On the other hand, when the temperature is high, non-ionic surfactants fail to dissolve in water, and the solution becomes cloudy. This temperature is called the cloud point. Water temperature when washing is closely related to the solubility of the surfactant. With increasing temperature, the solubility of an anionic surfactant increases, but the solubility of a non-ionic surfactant decreases. In the case of an anionic surfactant, the solubility temperature increases as the number of carbon atoms increases, and in the case of C_{14}, it dissolves at 48°C. Washing historic textiles at high temperatures will cause expansion, plumping, or bleeding of dyes, so the most suitable surfactants are those that enable washing at room temperature.

2.2.5 Hydrophilic-Lipophilic Balance (HLB)

The HLB (Hydrophilic-Lipophilic Balance) value indicates the surfactant's degree of affinity for water and oil, as an indicator of its action as a detergent. Values fall in the range of 0 to 20. The closer to 0, the higher the lipophilicity, and the closer to 20, the higher the hydrophilicity. Surfactants with an HLB value around 13-16 are used as detergents.

3. Wet cleaning historic textiles

Conditions for a surfactant in washing textile cultural properties are washing power, low CMC, usability at room temperature, neutrality, and low foaming. Surfactants are known to cause yellowing if they remain in fibres, and thorough rinsing is necessary.

3.1 Detergent selection

In the U.K., Synperonic™ N (nonylphenol ethoxylate) was used for washing historic textiles since the 1970s. This is a neutral non-ionic surfactant that does not ionize in water and is not affected by water hardness or electrolytes. However, it has low biodegradability and went out of use after 1995 due to the standards of the European Union. Thus, Fields et al.[3] examined 24 types of detergent and reported that the following types used in the U.S. satisfied requirements as detergents for historic textiles: the anionic surfactants Orvus® VA Paste (sodium lauryl sulphate, CAS No. 151-21-3) and Hostopan® T (N-Methyl-N-oleoyltaurine, CAS No. 97-80-3), and the non-ionic surfactants (neutral detergents) Dehypone® LS 45 (poly(oxyalkylene) alkyl ether, CAS No. 68439-51-0) and Synperonic™ 91/6 (poly(oxyethylene) alkyl ether, CAS No. 68439-46-3).

Sato et al.[4] conducted comparative testing of Dehypone® LS 54 with the same components but a higher cloud point than Dehypone® LS 45 from the clinical perspective of washing textile cultural properties. They reported that Dehypone® LS 54 exhibits an equivalent soiling washing effect in washing tests of artificially soiled cloth, despite a somewhat high CMC, and that it has high washing effectiveness for cotton cloth and is suitable for washing at room temperature.

Surfactants are environmental pollutants, so some may be subject to import restrictions. If a tested surfactant cannot be obtained, it is recommended to order a reagent with the same chemical identification number (CAS No.) from a chemical sales company, and, before using on cultural properties, conduct tests on soiling removal, foaming characteristics, and the number of rinses needed to eliminate bubbles.

If the surfactant is an undiluted solution, add carboxymethyl-cellulose (SCMC DP=200-500, DS=0.6-0.8) as a dispersant at a rate of 0.05% of the amount of water[5]. This is done to keep soiling dispersed in the washing bath from reattaching to fibres.

3.2 Dehypon® LS 54

Dehypon® LS 54 is a carboxylic acid-type non-ionic surfactant. The main component is poly(oxyethylene)alkyl phenyl ether (APE) of fatty acid alcohols. The number of carbon atoms in the alkyl group is 12-14 ($C_{12\text{-}14}$) with 5 mol of ethylene oxide and 4 mol of propylene oxide. The aqueous solution is neutral and has stable properties against acids and alkalis. Since it does not dissociate ions in water, it does not bond with minerals contained in hard water or mordants (metal salts of aluminium and iron) used in dyeing. The dissolution temperature (cloud point) is 30 ℃ , above which it becomes cloudy. BASF's CMC concentration is 0.010 g/l and tested CMC concentrations range from 0.4 to 0.598 g/l. In a washing test using artificially contaminated cloth, it was reported that a concentration of 0.3% (w/v) had the highest washing effect[6]. Biodegradable. Mainly used in the UK.

3.3 Dehypon® LS 45

Dehypon® LS 45 is a carboxylic acid-type non-ionic surfactant, the main component of which is poly(oxyethylene)alkyl phenyl ether (APE), an aliphatic alcohol. The number of carbon atoms in the alkyl group is 12-14 ($C_{12\text{-}14}$) with 4 moles of ethylene oxide and 5 moles of propylene oxide. The aqueous solution is neutral and has stable properties against acids and alkalis. Since it does not dissociate ions in water, it does not bond with minerals contained in hard water or mordants (metal salts of aluminium and iron) used in dyeing natural dyes. The dissolution temperature (cloud point) is 20°C, above which it becomes cloudy. BASF has a CMC concentration of 0.015 g/l and a tested CMC concentration of 0.598 g/l. The surface tension is 30 dyn/cm (approx.) at 0.1% and 25℃ . Biodegradable. Mainly used in the UK.

3.4 Orvus® WA Paste

The main component of Orvus® WA Paste is sodium lauryl sulphate (SLS) ($C_{12}H_{25}SO_4Na$)[7]. Aqueous solutions range from neutral to weak alkaline (pH 7.8), and they exhibit stability in hard water and alkalis. However, they are unstable at pH 7.0 or lower. The paste dissolves in lukewarm water (30-40 °C). Sulphate is added as an auxiliary. This has the action of promoting micelle formation, increasing adsorption of surfactant to fibres and soiling due to neutral electrolytes, and facilitating detachment of soiling. It has flexible action, adsorbing to protein fibres such as wool, and thus is suitable for fibres such as wool and silk whose feeling is important. CMC is 2.907 g/l (0.3%). Surface tension: 0.1%, 25°C, 53 dyn/cm (approx.) High foamability. The manufacturer recommends a 1% (w/v) aqueous solution. The surfactant has outstanding biodegradability. It is mainly used in the U.S.

4. Advisability of washing textile cultural properties

Fabric items such as clothing and towels for daily use are routinely washed for reasons of hygiene and aesthetics. However, museum collection pieces and textile cultural properties with recognized historical value cannot be washed in the same manner. Washing has the effect of removing soiling and oxides, stabilizing fibres, and restoring appearance, but there is a risk that material will be damaged by washing due to embrittlement brought on by the degradation of material with age. If an antique look due to ageing, or evidence, in the form of the added value of traces, soiling, or wrinkles due to use, is lost due to washing, it cannot be restored to the way they were. It is important to make an overall judgment on the advisability of washing, i.e., what will be achieved by washing a historic textile, what will be lost, what conservation/restoration steps should be taken, and what legacy should be left for future generations.

Table 19.3 Main surfactants advocated for wet cleaning historic textiles

Product name	CAS No.	Category	Chemical name Chemical formula Surface tension	CMC concentration (g/L)	HLB	Cloud point (℃)	pH
Dehypone® LS54 (BASF)	68439-51-0 (①)	Non-ionic	ethoxylated propoxylated alcohols（C_{12-14}） 5EO/4PO R-O-$(C_2H_4O)_{n/}(C_3H_6O)_mH$ (n=12-14) Surface tension: 0.1% 23℃ 29 dyn/cm (approx.)	0.4-0.59	n/a	30	7
Dehypone® LS45 (BASF)	68439-51-0 (①)	Non-ionic	ethoxylated propoxylated alcohols（C_{12-14}） 4EO/5PO R-O-$(C_2H_4O)_{n/}(C_3H_6O)_mH$ (n=12-14) Surface tension: 0.1% 25℃ 30 dyn/cm (approx.)	0.6 (0.06%)	n/a	20	6.5 - 7
Synperonic™ 91/6 (Croda)	68439-46-3 (②)	Non-ionic	polyoxyethylene (6) C_9-C_{11} alcohol	0.557 (0.06%)	12.5	48 - 56 (52)	6.6
Hostapon® T (Clariant GmbH)	97-80-3	Anionic	N-methyl-N-oleoyltaurate $C_{21}H_{41}NO_4S$	0.438 (0.04%)	n/a	n/a	7-8
Orvus® WA Paste (P&G)	151-21-3	Anionic	sodium lauryl sulfate (SDS) $C_{12}H_{25}SO_4Na$ Surface tension: 0.1% 25℃ 53 dyn/cm (approx.)	2.36 (0.24)	n/a	n/a	7.8

Equivalent CAS No. products of Japanese makers: ① Leox® CL-2008, 2010 (Lion) ② Laol® XA 60-50 (Lion)

5. Record preparation and washing tests

When determining the advisability of washing textile cultural properties, investigate and prepare a record of the historical background of the piece, traces of use, fibres, dyes, decorations, and other material techniques, sewing, soiled parts, and types of soiling. It is also necessary to test whether things like soiling, dyes, and fibres will dissolve in water or washing solution and whether dyes will bleed or discolour due to the degree of acidity of the aqueous solution. If a sample can be obtained, collect threads which have fallen off, or gather an extremely small amount of threads of each colour. If a sample cannot be obtained, drip testing of the aqueous solution can be performed at the edge of the textile, but there is a possibility a stain will appear. When examining irreversible steps like washing, involving major changes in the textile, it is best to conduct testing by taking a sample. For washing test methods, see Practice: "Soiling and dye dissolution testing."

5.1 Amount of detergent based on washing method

Adjust the amount of detergent according to the degree of soiling, using as a guideline 2 to 10 times the CMC of the surfactant used. In the case of an undiluted solution, disperse and add sodium carboxymethyl-cellulose (SCMC) as necessary as an anti-soil redeposition agent. Follow the use instructions for products containing auxiliaries, etc. Prepare the washing solution according to the washing method before starting washing. There are two specific methods.

① Method of preparing a washing solution with the prescribed concentration, applying it to a sponge, and directly permeating it into the textile
② Method of calculating the amount of water to suit the washing tub, adding detergent, and soaking the textile.

5.2 Washing tub and calculation of water amount

The washing tub used for washing textiles should be a white plastic tray, as it enables any colour in the water to be visible. There are methods suitable for washing larger items, such as making a washing table by covering a box with a plastic sheet. During preparation it is important to consider the method of draining a large amount of water. Calculate the amount of water to be poured into the washing tub for one wash using the following calculation formula[8].

Vertical length x horizontal length x water depth of washing tub (cm) =
Amount of water (litres)

Practice 1 Soiling and dye dissolution testing[9]

1. Samples

Threads which have fallen off or an extremely small amount of threads gathered from the textile.

2. Materials and equipment

The acidic aqueous solution, alkaline aqueous solution, water, washing solution, small dish, filter paper or absorbent cotton, eye dropper, tweezers

Fig. 19.5 Prewashing solubility test for dirt and dyes.

3. Method

1.Cut the sample into four pieces.
2.Place the filter paper or absorbent cotton on the small dish. Spread out the sample.
3.Drip acid, alkali, washing water, and washing solution (washing concentration)* onto the samples.
4.Observe elution of soiling and dye and colour changes.

*Adjust the concentration and amount of detergent according to the size of the textile and the degree of soiling, using as a guideline 2 to 10 times the surfactant CMC. Add sodium carboxymethyl-cellulose (SCMC) as a dispersant and anti-soil redeposition agent at a rate of 0.05% (w/v)of the amount of water.

Practice 2 Wet cleaning textiles

Practice with white or non-bleeding flat textiles.


Fig. 19.6 Wet cleaning a textile.

1. Materials and equipment

Net (cotton, synthetic fibre), thread (white), needle, vat or the like (washing tub), synthetic fibre net or polyester sheet, nitrile gloves, sponge (synthetic or natural fibre), plastic beaker, white towel or cotton sheet, electric fan, stainless steel marking pins, acrylic sheet, test tube (small), pH testing paper, thermometer, polyethylene sheet, drying stand made of a soft board covered in graph paper and wrapped with polyethylene sheet.


Fig. 19.7 Protection of damaged areas with cotton or nylon net.

2. Textile protection

Cover damaged parts with a net (if obtainable, a cotton type which absorbs water and adheres to the textile is best) and sew in place with thread.


Fig. 19.8 Sponging during wet cleaning.


Fig. 19.9 Towel dying.

3. Method

1. Prepare the washing tub. Washing should be done in a waterproof container such as a sink, plastic container, or container covered with a polyethylene sheet.
2. Prepare two synthetic fibre nets or hard polyester sheets. Place one of the two on the textile. Turn over the textile, cover it with the other net or sheet, so the textile is sandwiched between, and then turn it back over.
3. Wash by pressing gently with a sponge on both sides. Record the water temperature, water pH, and washing time.
4. Check as follows for detergent remaining after rinsing. Prepare two small test tubes. Place tap water in one, and rinse water in the other. Hold each between your thumb and index finger, and simultaneously shake. The way rinse bubbles subside should be the same as for tap water. If there is a difference further rinsing is required.
5. To dry, absorb water with a towel etc. For a soft finish, dry on cloth, and for a taut finish, dry on glass or an acrylic sheet. Adjust the shape and align the weave when half dry. For pieces with a 3D shape such as apparel, place scrunched synthetic fibre net inside the garment or object, adjust the shape, and dry. Then use a fan to circulate the air and dry it quickly.

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20

Bleaching

Fibre deterioration causes yellowing, and dirt may result in staining. Bleaching is a treatment which removes these colourings and regains the whiteness of the fibres. Bleaching dissipates colour by decomposing the structure of coloured matter through the chemical reactions of oxidizing and reducing agents. However, substances other than coloured matter, such as fibre polymers, are also chemically affected and may deteriorate due to bleaching processes. Bleaching of historic textiles is a treatment which emphasizes aesthetic appearance. It also presents an ethical problem in that this treatment is contradictory to the whole purpose of conservation, which is to stabilize the material of the artefact This process is only considered when yellowing or staining is still visually intrusive after wet cleaning and visual recovery is necessary for presentation. The bleaching of historic textiles is limited to white cellulose and some synthetic fibres such as polyester. Since silk and wool, which are proteins, have different properties, they should not be bleached.

In Europe, linen and cotton lace and white ceremonial robes have been culturally valued for their whiteness. From the 1960s onwards, case studies have been reported on bleaching lace and ceremonial dresses for display in museums[1]. Jentina Leene, a textile scientist at the Delft University of Engineering (The Netherlands), described the effect of bleach on fibres and proposed a formula for historic textiles as below. which became the starting point of bleaching used in textile conservation today.

Table 20.1 Bleaching formula by Leene[2]

Fibre・Chemical reagent	Effect	Amount
Cellulosic fibre	-	100 g
Hydrogen peroxide (H_2O_2 30% solution	Oxidative bleach Weakly acidic (storage).	50 ml
Sodium hydroxide (NaOH)	Speeds up decomposition of hydrogen peroxide and promotes the formation of acid oxycellulose. Alkali.	5 g
Sodium carbonate（Na_2CO_3）	Speeds up decomposition of hydrogen peroxide and promotes the formation of acid oxycellulose. Alkali.	5 g
Sodium metasilicate（Na_2SiO_3）	Controls the extent of decomposition of hydrogen peroxide. Alkali.	20g
Water	Solvent	1000 ml

Bleaching requires the combination of a bleaching agent, decomposition promoter, controlling agent and solvent. It is also necessary to carefully monitor the pH and time during operation. Bleaching reagents are easily hydrolysed so control is difficult, and fibres are easily damaged. Bleaching is not an easy treatment to perform. Although the chemical theory of bleaching is now better understood, and formulas have been studied to make it safe for usage, there are very few case studies of bleaching historic textiles today. Research on bleaching is more advanced in paper conservation. When seeking information about bleaching, care must be taken since there are differences in methodology and material to those of textiles.

1. The colour of organic dirt, and bleaching[3]

The colour of organic dirt originates in the chromophore groups of materials contained in the dirt or stains derived from conjugated double bonds.

When cellulose, the main component of plant fibres such as linen and cotton, deteriorates, hydroxyl groups (—OH) are replaced by carbonyl groups (—CO—) and carboxyl groups (— COOH) and the fibre appears yellow. This is due to an increase of double bonds since the characteristic colour moves from the higher energy UV adsorption into the visible lower energy part of the spectrum. Redox reactions break the bonds to restore the whiteness of the fibre and turn it back to the original colourless substance. Since the breaking of the molecular chain by bleaching occurs not only in chromophore groups but also in fibre polymers, it reduces the degree of polymer chains resulting in fibre deterioration. Here, the durability of the whiteness of the fibre gained by bleaching is limited and the colour will return with oxidation, leading to further decay.

It is clear from the chemical theory of bleaching that new bleached fabric is not likely to last as long. Therefore, it is desirable to choose unbleached fabric for conservation use.

2. Bleaching by oxidation and reduction

Bleaching is the redox reaction of a substance. Oxidation is a reaction whereby oxygen is combined with a substance or hydrogen is removed from that substance. Reduction is a reaction whereby oxygen is removed from a substance, or hydrogen combines with the substance. When a substance releases electrons (e^-), it is oxidized, and when a substance receives electrons (e^-), it is reduced.

Oxidative bleaching may be performed by bleaching with light or bleaching with reagents. Oxidative bleaching reagents are either chlorine-based or oxygen-based and for conservation use, oxygen-based reagents are preferred since they do not leave any residue.

Reductive bleaching is performed using reagents. Compared with oxidative bleaching, fibres treated with reductive bleaching agents tend to oxidize with the surrounding air faster so that the colour returns more quickly. At the same time, reduction bleaching exhibits alkalinity when it is hydrolysed, which in some effect stabilizes cellulose fibres[4-5]. Reducing agents not only bleach fibres but also reduce oxidized insoluble stains, rendering them soluble in water so that they can be removed (e.g., iron oxide). To find out whether brown spots are due to metal residue, test papers can be used to detect metal ions.

Metals catalyse bleaching agents, so reverse osmosis membrane-filtered water is recommended[6]. Distilled water or deionised water sold as a reagent may be used. The container must be made of plastic or glass. When bleaching, it is important to know the reasoning behind the discolouration of the dirt, stain or fibre, so that a suitable bleaching agent, formula, and treatment can be selected.

*Metal mordants, blood and iron stains will react to oxidative bleach and may cause holes to form where stains are located/ metal is attached to fibres.

3. Oxidative bleaching

Oxygen decomposes into “activated oxygen” which reacts with coloured substances and oxidises them forming “colourless” materials. The speed of this oxidation depends on the concentration of the reagent, pH, temperature, and time. Metals, such as copper and iron, promote oxidation as catalysts, so the reaction can no longer be controlled. Therefore, this type of bleaching cannot be used for textiles with metal components. It cannot be used with stains of metal origin. Deionized water should be used. Stains which respond to oxidative bleaching are yellowing fibres or stains of organic colouring matter.

"Oxidative bleach" (oxidizing agent) Oxidizing coloured substances to "Colourless" by either of the reactions below	"Coloured matter" (oxidized)
・Give away O ・Receive H ・Receive e^-	⇒ ・Recieve O ・Give away H ・Give away e^-

3.1 Sunlight, ultraviolet radiation bleaching[7]

Bleaching with light is an oxidative bleaching reaction wherein the wetted cloth is exposed to sunlight and ultraviolet radiation destroys the colouring matter. Atmospheric oxygen is decomposed by ultraviolet rays and ozone (O_3) is generated which acts as an oxidizing agent with water. It bonds with the colouring matter and breaks the molecules to form colourless matter. Traditional sunlight bleaching uses this mechanism. Case studies have been reported where an ultraviolet lamp was used for bleaching prints and drawings.[8]

When the air is exposed to ultraviolet light, oxygen decomposes and ozone is generated.

$$3O_2 \xrightarrow{UV} 2O_3$$

Fig. 20.1 1950's poyester wedding dress was bleached with hydrogen peroxide after wet cleaning. (Photo: Ian MacLeod, Rinske Car.)

Fig. 20.2 Polyester fibre wedding dress during treatment. (Photo: Ian MacLeod, Rinske Car.)

3.2 Reagent bleaching

Oxidative bleaching agents used for historic textiles are given below. These chemicals decompose in an aqueous solution, generating oxygen which bonds with the colouring matter thus turning it into a colourless matter.

3.2.1 Hydrogen peroxide (H_2O_2)[9]

Hydrogen peroxide tends to decompose into oxygen and water during storage. Therefore, it is marketed as being adjusted to a more acidic pH to avoid this complication. At the time of use, the decomposition of the dye is accelerated by making it weakly alkaline or by heating. However, treatment with pH 8-9 does not change the appearance much compared to pH 10[10]. For this reason, it is desirable to use an alkaline aqueous solution that is as close to neutral as possible in the treatment of historic textiles because of its effect on the material. Hydrogen peroxide can be stored in an airtight container for about five years. Figures 20.1-2 show an example of the use of hydrogen peroxide treatment on an early polyester wedding dress in Australia. It was bleached to recover the whiteness as the aesthetic appearance was considered important when displayed at a museum for an exhibition[11].

3.2.2 Sodium perborate ($NaBO_3\ nH_2O$)[12]

Sodium perborate comes as a white crystalline powder and has low solubility in water (it takes time to dissolve). If used together with hydrogen peroxide, the rate of decomposition, promoted by alkali (sodium hydroxide, sodium carbonate) is controlled. Perborate contains two bridged peroxyl, or O_2 moieties so the reaction with water releases one of them, and hydrogen peroxide (H_2O_2) is formed in solution. Thus, the decomposition rate of hydrogen peroxide can be suppressed and the bleaching action can be sustained. Since it has a bleaching action by itself, it may be used for bleaching.

$$O_2 + 2e^- + 2H^+ \ Na_2B_2O_4(OH)_4 + 4H^+ \rightarrow 2H_2O_2 + B_2(OH)_4{}^{2-} + 2Na^+$$

$$Na_2B_2O_4(OH)_4 + 4H^+ + 4e^- \rightarrow 2H_2O_2 + B_2(OH)_4{}^{2-} + 2Na^+$$

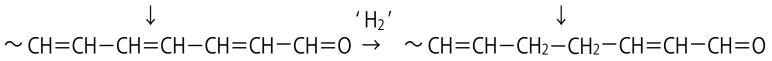
Decomposition of sodium perborate.

Fig. 20.3 Iron indicator test paper used to identify iron in the brown stain.

4. Reductive bleaching [13]

4.1 Destruction of pigment groups and "decolourisation"

Reductive bleaching takes away oxygen or gives electrons to the coloured substance destroying it and making it "colourless". Reductive bleaching agents are commonly used to remove yellowing from cellulosic fibres such as cotton and flax. The reducing agent has the effect of reducing water-insoluble metal stains such as iron oxide and dissolving them in water. An iron test may be used to confirm if the stain is of iron origin.



$$\sim CH=CH-CH=CH-CH\overset{\downarrow}{=}CH-CH=O \xrightarrow{'H_2'} \sim CH=CH-CH_2\overset{\downarrow}{-}CH_2-CH=CH-CH=O$$

Breaking of double bonds by the addition of hydrogen.

"Reductive bleach" (reducing agent) Reducing coloured substances to "Colourless" by either of the reations below		"Coloured matter" (reduced)
・Recieve O (bond) ・Give away H ・Give away e^- (give)	⇒	・Give away O ・Recieve H ・Recieve e^-

4.1.1 Sodium borohydride ($NaBH_4$)[14-15]

Sodium borohydride, which comes as a white powder, reduces oxides of colouring matter to a colourless matter. The aqueous solution is strongly basic due to the decomposition products. The pH of a 1 % solution is pH 9. Since hydrogen is generated while decomposing, treatment should be carried out in a well-ventilated room. Although the colour may return quite quickly when it oxidizes in the air, cellulose fibres become stabilized by this treatment. The reagent can be kept sealed for about 3 months

4.2 Reduction and dissolution of coloured substances

4.2.1 Oxalic acid ($H_2C_2O_4$)[16]

Oxalic acid comes in a form of a white powder and is a reducing agent. It reduces insoluble oxides, rendering them water-soluble thus making them easy to wash out. It has been used to remove iron stains from paper and textiles. For example, oxalic acid reduces insoluble ferric (III) oxide (Fe^{3+}) and transforms it into water-soluble ferrous (II) oxide (Fe^{2+}). A test paper can be used to determine whether brown spots are due to iron.

$$\underset{\text{iron (III) oxide}}{Fe_2O_3} + \underset{\text{oxalic acid}}{(COOH)_2} \rightarrow \underset{\text{iron (II) oxide}}{2FeO} + \underset{\text{carbon dioxide}}{2CO_2} + \underset{\text{water}}{H_2O}$$

$$\underset{\text{Iron (II) oxide}}{FeO} + \underset{\text{oxalic acid}}{(COOH)_2} \rightarrow \underset{\text{iron(II) oxalate (water soluble)}}{Fe(COO)_2} + \underset{\text{water}}{H_2O}$$

Practice 1 Oxidative bleaching with hydrogen peroxide

It is important to compare and understand the concentration and types of bleaching agents, and their use and methods of application on historic textiles through practice. What is shown here is not a guideline for use in the actual bleaching treatment of historic textiles. It is important to learn about the results of bleaching textiles in these ways and how they serve the conservation purpose of long-term stabilization. Do not use metal tools because the chemicals are highly corrosive.

Prepare a discoloured (yellowed) cellulosic fabric for practice. If available, measure the same area before and after treatment with a spectrophotometer. Calculate the colour difference ⊿ E using the CIEL*a*b* value as below to verify the effectiveness of the treatment. A website such as ColourMine.org offers a free Delta E Calculator service. These online services make the calculation of colour change easy by simply inputting spectrometer CIEL*a*b* values. The formula for calculating colour difference is:

$$\varDelta E= \{ (L^*_1-L^*_2)^2+(a^*_1- a^*_2)^2+(b^*_1-b_2{}^*)^2\}^{1/2}$$

Fig. 20.4 Use a white plastic tray.
Place a polyester sheet under and over the textile and submerge in the bleaching solution.

1. Chemical reagents

- Hydrogen peroxide (H_2O_2) solution
- Sodium perborate ($NaBO_3\,n\,H_2O$)
- Acetic acid (for adjusting pH)
- 25 -30% ammonia solution (for adjusting pH)
- Deionised water or distilled water (purified water)

2. Tools

Polyethylene tray (2), polyester sheet (2), large glass or polyethene beaker (2), labels, glass rod, pipet (2), thermometer (100℃), pH indicator strips (pH 0-14), lab coat, chemical resistant gloves/nitrile gloves, goggles.

3. Fomula[17]

① Weight of textile (g)

② Liquor to weight ratio fabric weight : water weight = 1 : 100

③ Total liquor (T.L.)= fabric weight (g) x 100

④ Required working strength of hydrogen peroxide (H_2O_2)= 1.5% (v/v)

Strength of concentrated hydrogen peroxide available
(eg. 30% (v/v), marked on the bottle).

The required amount of hydrogen peroxide is calculated bellow on the right.

$$Z = \frac{X \times Y}{V}$$

X= strength of concentrated hydrogen peroxide required (%)
Z = the amount of working strength hydrogen peroxide required (ml)
V = strength of concentrated hydrogen peroxide available (%)
Y= total volume of water (ml)

⑤ Sodium perborate ($NaBO_3\,n\,H_2O$) 6-7(g/1000ml)

4. Procedure

1. Dissolve sodium perborate in water. This will take time (2 hours)
2. Add the hydrogen peroxide to 1.
3. Measure the pH with a pH indicator strip.
4. Adjust to pH 8.5 with small amounts of acetic acid and ammonia.
5. Place the textile onto a clear polyester sheet and wet it out with deionized water
6. In the empty tray, pour in the hydrogen peroxide and sodium perborate solution.Mix and measure the pH, the bleaching agent works best in an alkaline condition.
7. Submerge the textile into the bath.
8. Place a clear sheet over the object to help it remain fully submerged.
9. Leave for 1 hour. Monitor regularly.
10. Remove the textile from the bath and rinse well.
11. Blot/ use a towel to absorb water and leave it to air dry.

*The bleaching agent works best at around 40-50 ℃ . The treatment may be carried out using a double bath.

Practice 2 Bleaching by reduction with sodium perborate

1. Chemical reagent

- Sodium perborate ($NaBO_3$ n H_2O)
- Acetic acid for adjusting the pH
- Deionized water or distilled water (purified water)

2. Formula[19]

① Weight of textile (g)
② Liquor to weight ratio fabric weight : water weight = 1 : 100
③ Total liquor (T.L.)= fabric weight (g) x 100
④ 10% (v/v) sodium perborate ($NaBO_3$ n H_2O) solution (10g/ l000m)
⑤ Required pH of working solution = pH 7.0 (adjust with acetic acid)

3. Procedure

1. Dissolve sodium perborate in water. Wait until the bubbling has stopped.
2. Adjust the pH to 7 with boric acid.
3. Place the textile onto a clear polyester sheet and wet it out with deionized water.
4. In the empty tray, pour in the bleaching solution.
5. Submerge the textile into the bath.
6. Place a clear sheet over the object to help remain fully submerged.
7. Leave for 15 minutes. Monitor regularly.
8. Remove the textile from the bath, rinse well and measure the surface pH.
9. Blot out with a towel and leave to air dry.

Practice 3 Bleaching by reduction with sodium borohydride

1. Chemical reagent

- Sodium borohydride ($NaBH_4$)
- Ammonia water for adjusting the pH
- Deionized water or distilled water (purified water)

2. Formula[18]

①Weight of textile (g)
②Liquor to weight ratio fabric weight : water weight = 1 : 100
③Total liquor (T.L.)= fabric weight (g) x 100
④1% (w/v) sodium borohydride ($NaBH_4$) in water (1g/100ml)

3. Method

1. Dissolve sodium borohydride in water. Wait until the bubble has stopped.
2. Measure the pH. Borohydride self-buffers to pH 9.0.
3. Place the textile onto a clear polyester sheet, put it in a polyethylene tray and wet it out with deionized water.
4. In another empty polyethylene tray, pour in the bleaching solution.
5. Submerge the textile into the bath.
6. Place a clear sheet over the object to help remain fully submerged.
7. Leave for 15 minutes. Monitor regularly.
8. Remove the textile from the bath, rinse well and measure
9. Blot the water with a towel and dry indoors.

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21 Enzymes

Enzymes are proteins derived from organisms that act as a catalyst to assist the decomposition of organic substances. In textile conservation, enzymes are used to remove old starch or proteinaceous stains or to remove sizing from new fabrics to be used for support or display. When starch and protein become denatured and solidified over the years, it becomes difficult to remove. When trying to remove these kinds of materials, the first step to consider is whether they can be removed by mechanical means. Secondly, consider whether they can be removed by supplying moisture, steam, water, or heat to make them swell and soften. Thirdly, consider whether they can be dissolved in an aqueous solution, detergent, or solution of different pH, and finally, whether they can be removed using an enzyme. In principle, since each enzyme acts only on specific substances, the components of the material or dirt must be identified first, and a suitable enzyme should be selected accordingly.[1]

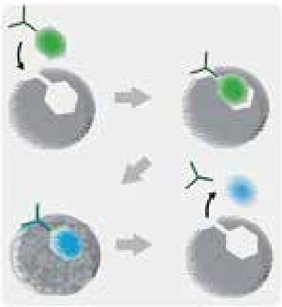

Fig. 21.1 Image of an enzyme as a keyhole (enzyme), which decomposes the matching matter.

1. Properties of enzymes

The function of an enzyme can be understood by the concept of a “key and keyhole”. When an enzyme swells up in the water at a suitable temperature, it assumes a three-dimensional spherical shape. It then reacts only with a substrate present at a specific active site, decomposing it by catalytic action to release products. At the same time, the enzyme returns to its original molecular state and then binds to the next substrate. If the key (substrate) and keyhole (type of enzyme) do not correspond, the enzyme does not work.

Some enzymes may have low substrate specificity, meaning they are not very selective as to the sequence they cleave, or some may have high substrate specificity, meaning they are highly selective and cleave only specific sites. For enzymes used in conservation, they should be of known origin and should be pure. This is because if the substrate specificity is low, they may unnecessarily damage the material. Enzymes have an optimum temperature and pH at which they are activated, and beyond these optimum values, they are denatured and are longer active. As a guideline, enzymes of plant origin have an optimum temperature of about 40 to 60°C, whereas enzymes of animal origin have an optimum temperature of about 35 to 50°C. Although storage depends on the enzyme, they are usually placed in a sealed container and kept in a dry, dark place at about 0-30°C. The optimal pH also differs depending on the enzyme. Since textile materials (fibres or dyes) are more easily damaged by the pH than the enzyme, it is preferable to select an enzyme which is activated at a neutral pH. The reaction time varies depending on the hydrophilic or hydrophobic nature of the dirt, the permeability of water, temperature, and condition of the textile. Enzymes can rapidly decompose the substrate as a catalyst, so only a very small amount is necessary for conservation treatments. Although it depends on the amount of dirt or stains, a 0.01-0.1% (w/v) aqueous solution is often sufficient.

Water is necessary for activating the enzyme. However, metal salts in water may interfere with the catalytic action of the enzyme, thus deionized water or reverse osmosis membrane-filtered water should be used[2].

1.2. How to use enzymes

An enzyme treatment may be carried out as a full treatment where the whole textile is immersed in water[3] or as a partial treatment where part of the textile is treated. Water and alcohol can be used together when too much wetting of the textile is undesirable or quick drying is necessary. A wet compress method can introduce a slight amount of moisture whereby enzyme solution is applied to the unwanted matter with a brush over a nonwoven synthetic membrane or a special osmosis membrane such as Gore-tex® and Sympatex®. The poultice method is also possible by mixing enzymes with methylcellulose or carboxymethylcellulose to form a gel, applied over a membrane to control rapid penetration of the enzyme solution into the textile[4]. Readymade paper compresses with enzymes are available commercially[5], and there is an example where these were used to remove starch paste from a historic textile[6]. The palm of the hand or a low-temperature iron is used when warming the enzyme in partial treatments.

At the end of a full treatment by application of ethanol[7] or by immersion in water, the pH of the aqueous solution is changed (adjusted by acetic acid or ammonia) to stop the action of the enzyme and denature it, and it is then removed by rinsing. Research shows that, when using very small quantities of enzymes for partial treatment, colour change of the material is negligible, even if some residue remains[8]. The decrease in the degree of polymerization of the fibres (fibre weakening) is more affected by the pH of the water (pH 4.5-5.5, acidic) than the enzyme itself[9].

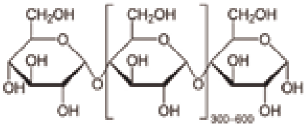

Fig. 21.2 Amylose

When cleaning using enzymes, the type of dirt is first identified, and a pure enzyme which acts specifically upon it is selected. Then, the temperature, pH, time, and method of contact with the substrate are planned to activate the enzyme without damaging the fabric. If any enzyme remains in the fabric, it will decompose the newly introduced substance if it is of the same chemical compound as that removed. Therefore, in the case of retreating an artefact with adhesive for conservation, a combination regimen of deactvation, removal and application must be considered. Enzyme cleaning is not an easy treatment to perform, and it is essential to consider the options and plan carefully. Table 21.1 shows the main enzymes, substrates, optimum temperatures, and pH used in textile conservation.

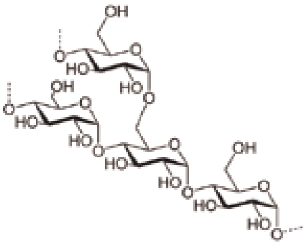

Fig. 21.3 Amylopectin

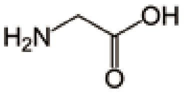

Fig. 21.4 Grycine

2. Enzymatic degradation of starch

Starch is a carbohydrate (polysaccharide)with a molecular formula of $(C_6H_{10}O_5)_n$. It is a polymer with a large number of α-glucose molecules and contains amylose and amylopectin. In starch, the glucose is joined by 1,4'-α-glucose bonds, with side chains of 1,6'-α-glucose bonds branching off from the main chain. Although amylose has almost no branching, amylopectin has a branched structure.

The enzymes α-amylase and β-amylase cleave the 1,4 linkages of starch and decompose it into α-D-glucose (sugar). Starch which does not dissolve in water is turned into sugar which can be washed out with water.

2.1 Enzymatic degradation of protein

Protein is a generic term for organic compounds having both an amino group (—NH_2) and a carboxyl group (—COOH), and they are polymers in which many such units are joined together. The acid amide bond seen in amino acid sequences is referred to as a peptide bond. Protease which decomposes and cleaves this peptide bond is an example of breaking up proteins.

Table 21.1 Enzymes used in textile conservation[10]

Enzyme	Substrate	Product	Optimum ℃ /pH
Diastase α — amylase & β — amylase	Starch	Dextrin	40℃ pH 4.5 – 5.5
α — amylase	Amylose Amylopectin	α -D-glucose	40 – 70℃ pH 5.5 – 6.0
β — amylase)	Amylose Amylopectin	α -D-glucose	50 – 55℃ pH 5.5
Cellulase	Cellulose	α - β -glucose (cellobiose)	50℃ pH 4.5
Protease	Protein (e.g. leather)	Protein fragments + amino acid	30 – 40℃ pH 6.0 – 8.5
Trypsin	Proteins	Protein fragments + amino acid	60℃ pH 7.0 – 9.0
Gelatinase	Hydrolysed collagen (e.g. gelatine, animal glue)	Protein fragments + amino acid	40℃ pH 8.0 – 9.0
Lipase	Fats	Glycerine + fatty acid	37℃ pH 4.0 – 5.0

3. Spot tests

A spot test is a simple method to identify starch, protein, and fats. Testing agents should be stored in a brown bottle glass bottle and kept in a cool dark place.

3.1 Starch

Detection reagent: iodine solution

Method of preparation: dissolve 2 g of potassium iodine and 1 g of iodine in 100 ml distilled water.

①Place the test sample on a dish.
②Apply a drop of test solution.
③Observe the colour. The starch will turn dark purple.

3.2 Protein

Detection reagent: 0.8% Fuchsine S solution

Method of preparation: dissolve 0.8 g Fuchsine S in 100 ml distilled water.

①Place the test sample on a dish.
②Apply a drop of test solution.
③Wash the sample with water.
④Protein will stain pink.

3.3 Fats Sudan Black B

Detection reagent: Sudan Black B

Method of preparation: dissolve Sudan Black B in ethanol : water (30:20 ml) until saturated. Use the top part of the liquid.

①Place the test sample on a dish.
②Apply a drop of test solution.
③After 30 minutes, wash with water : ethanol (2:3) and rinse with water.
④Fats will stain black.

Practice 1

Enzyme treatment on starch with α -amylase, full immersion treatment

It is important to compare and understand the type of enzymes, their use in textiles, and methods through practice and learn how they serve the conservation purpose of long-term stabilization of the textile. What is shown here is not a guideline for use in the actual enzymatic treatment of historic textiles, but exercises to teach the principles of enzyme application.

1. Chemical reagents

- α--amylase (origin *Bacillus subtilis*)
- Deionized water or water made by reverse osmosis
- Acetic acid
- Ethanol

2. Sample

A practice fabric containing starch.

3. Tools

Polyethylene tray (2), polyester clear sheet (2), soft brush, large glass or polyethylene beaker (2), labels, glass rod, pipet (1), thermometer (100℃), pH indicator strip (pH 0-14), lab coat, nitrile gloves, goggles, heater or hot plate, towels, iron.

4. Formula

①Concentration of enzyme 0.01% (w/v) (0.01 g/100 ml)
②Liquor to weight ratio fabric weight : water weight = 1 : 10
③Total liquor (T.L.) (ml) = 10 x fabric weight (g)
④Temperature: 40℃
⑤pH=5.5-6.0
⑥Duration: 40-120 minutes
⑦Rinse with ethanol or 0.1% acetic acid (to denature)
⑧Rinse well, more than twice.

5. Procedure

1. Place the textile onto a clear polyester sheet, put it in a polyethylene tray and wet it out with deionized water.
2. Dissolve the enzyme in 40 ℃ water and measure the pH with a pH indicator strip. Adjust the pH to pH 5.5-6.0 with acetic acid.
3. Placed on a polyester sheet, submerge the textile into the bath.
4. Maintain the bath at 40℃ by a double boiler or using a hot plate or a heater.
5. Leave for 40-120 minutes and observe regularly.
6. Brush the surface of the textile to remove the starch.
7. Remove the textile from the bath and rinse well with ethanol or water above the optimum pH (around pH 7) to denature the enzyme.
8. Blot out with a towel and leave to air dry.

Practice 2

Enzyme treatment on starch with diastase, full immersion treatment

1. Chemical reagent

- Diastase (α -amylase and β -amylase from malt)
- Deionized water or water made by reverse osmosis
- Acetic acid
- Ethanol

2. Sample

A practice fabric containing starch.

3. Tools

Polyethylene tray (2), polyester clear sheet (2), soft brush, large glass or polyethylene beaker (2), labels, glass rod, pipet (1), thermometer (100℃), pH indicator strip (pH 0-14), lab coat, nitrile gloves, goggles, heater or hot plate, towels, iron.

4. Formula

① Concentration of enzyme 0.1%(w/v) (0.1g/100 ml)
② Liquor to weight ratio fabric weight : water weight = 1 : 10
③ Total liquor (T.L.) (ml) = 10 x fabric weight (g)
④ Temperature 40℃
⑤ pH= 4.5-5.5
⑥ Duration 40-120 minutes
⑦ Rinse with ethanol or 0.1% acetic acid (to denature)
⑧ Rinse well, more than twice.

5. Procedure

1. Place the textile onto a clear polyester sheet, put it in a polyethylene tray and wet it out with deionized water.
2. Dissolve the enzyme in 40 ℃ water and measure the pH with a pH indicator strip. Adjust the pH to pH 4.5-5.5 with acetic acid.
3. Placed on a polyester sheet, submerge the textile into the bath.
4. Maintain the bath at 40℃ by a double boiler or using a hot plate or a heater.
5. Leave for 40-120 minutes and observe regularly.
6. Brush the surface of the textile to remove the starch.
7. Remove the textile from the bath and rinse well with ethanol or water above the optimum pH (around pH 7) to denature the enzyme.
8. Blot out with a towel and leave to dry indoors.

Practice 3

Enzyme treatment on protein with protease, full treatment

1. Chemical reagent

- Protease
- Deionized water or water made by reverse osmosis
- Acetic acid
- Ammonia water
- Ethanol

2. Sample

A practice fabric containing starch.

3. Formula

①Concentration of enzyme 0.01% (w/v) (0.01 g/100 ml)
②Liquor to weight ratio fabric weight : water weight = 1 : 10
③Total liquor (T.L.) (ml) = 10 x fabric weight (g)
④Temperature 40℃
⑤pH= 6.0-8.5
⑥Duration: 40-120 minutes.
⑦ Rinse with ethanol or diluted acetic acid or alkali below or above the optimum pH (denature)
⑧Rinse well, more than twice.

4. Procedure

1.Place the textile onto a clear polyester sheet, put it in a polyethylene tray and wet it out with deionised water.
2.Dissolve the enzyme in 40℃ water and measure the pH with a pH indicator strip. Adjust the pH to pH 6.0-8.5 with acetic acid and ammonia. pH 7.0 is desirable for the material.
3.Placed on a polyester sheet, submerge the textile into the bath.
4.Maintain the bath at 40℃ by a double boiler or using a hot plate or a heater.
5.Leave for 40-120 minutes and observe regularly.
6.Brush the surface of the textile to remove the starch.
7.Remove the textile from the bath and rinse well with ethanol or water below pH 6.0 or over pH 8.5 to denature the enzyme. Rinse well with water more than twice.
8.Blot out with a towel and leave to air dry.

Practice 4

Enzyme treatment on starch with α -amylase, spot treatment

This is a practice to remove the paper from a fabric adhered with starch using direct or poultice (compress) applications. Partially apply enzymes or contact compresses to the cloth to which the paper is attached.

1. Chemical reagent

- α -amylase (origin *Bacillus subtilis*)
- Deionized water or water made by reverse osmosis

2. Sample

Fabric with paper attached by starch adhesive.

3. Formula

① Concentration of enzyme 0.01% (w/v) (0.01g/100 ml)

4. Procedure

4.1 Application with brush

1. Place a piece of polyester non-woven fabric onto the starched area of the paper.
2. Take a small amount of enzyme solution on a brush and apply it over the non-woven fabric.
3. Warm the area with the palm (hand iron) or an iron heated to 40℃.
4. Release the paper and fabric.

4.2 Application with poultice

1. Apply a small amount of enzyme solution onto a piece of blotting paper or fabric to make a poultice
2. Place a polyester non-woven fabric over the starched area and apply the poultice.
3. Warm the area with the palm (hand iron) or an iron heated to 40℃.
4. Release the paper and fabric.
5. Apply a small amount of ethanol to the treated area and soak up the residue with blotting paper.

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22 Reinforment Methods

Textile conservation is often thought to be about mending tears with fabric, needle, and thread. This is only one aspect of its discipline. The primal aim for conserving a textile is the stabilization of its condition. Any support method of the textile containing a new support, joining with a needle and thread or an adhesive, will affect the textile because it is interventive. When choosing a method to stabilize a textile, priority is given towards physical support with a preventive conservation strategy in mind before direct intervention. The decision depends upon the textile's shape, material, the technique of manufacture, degradation, use, storage, display, and availability of materials. Basic methodologies are 1) physical support of the textile (mounting), 2) full or partial support of the damaged area of the textile, often with fabric support, and 3) direct application of fixing agent such as adhesive into the fibre (consolidation).

Basic reinforcement method [1]

① Method of physically supporting the entire dyed textile (mounting)
② A method of joining a new cloth to the entire dyed textile or part of the damaged part (fabric support).
③ Method of directly introducing a bonding agent (adhesive) into the fibre (consolidation)

1. Physical support method without joining with the textile (mounting)

- External mount
- Internal mount

2. Physical support methods by joining the textile with new support

- Support from the reverse face..
- Support from the face.
- Support from both faces (sandwich).

2.1 Joining methods of the textile with the new support material.

- Cover (loose)
- Stitch

3. Bonding fibres with adhesives (consolidation)

- Liquid impregnation method (coagulation)

4. Selecting a support material

When selecting a support material, consider various aspects of compatibility with the textile.

Chemical compatibility:
- Natural (cellulose, protein)
- Synthetic (polyester, nylon)
- Chemical stability
- Hygroscopic nature
- Static nature

Fabric structure:
- Woven fabric
- Knit fabric
- Non-woven fabric
- Weave count
- Density
- Fabric weight

Surface texture:
- Smoothness
- Abrasiveness

Visual appearance:
- Transparency
- Sheen
- Colour
- Pattern

Texture:
- Handling texture
- Visual texture

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23 Stitch Support

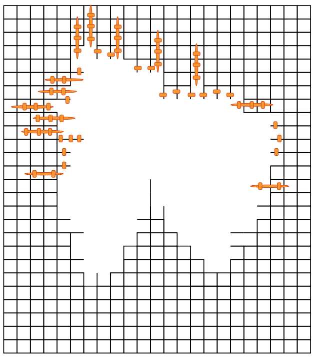


Fig. 23.1 Reinforcement diagram of support stitches

Fig. 23.2 Damage of a 19th-century Kashmir shawl.

Fig. 23.3 After support stitching, obverse.

Fig. 23.4 After support stitching, reverse.

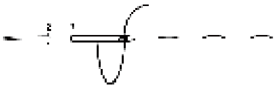
The main component of textiles is fabric. Fabric is manufactured for the purpose of wearing, wrapping, draping, covering, or cladding the body, or protecting an object from the environment. Fibres with pliability, durability, and hygroscopic properties, together with processing techniques, are selected according to the end use. Fabric can be broadly classified as nonwoven fabric, wherein fibres are felted and given a surface treatment, or fabrics where the fibres are organized into threads and woven into a cloth.

Thread is one of the components of woven cloth and behaves in the same way as cloth. When joining pieces of cloth, the thread is passed through a needle and pierced through the cloth, passing the thread between the layers of material. The thread expands, contracts, and moves together with the movement of the cloth, but once the thread is anchored, it cannot be undone. Thus, the thread is a suitable material to connect flexible fabrics that constantly change their form. It has previously been mentioned that the main purpose of the conservation of historic textiles is the "stabilization of condition", which differs from the functional recovery required in apparel (consumables). Every culture has its traditional way of repairing clothes, e.g., mending or darning[1]. Since this is a temporary "reinforcement" to permit clothes to be reused, some of these techniques are not always suitable for historic textile treatments. At times, examples of these traditional mending techniques may be conserved as textile cultural heritage.

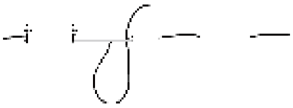
On the other hand, in Japan, even kimonos collected in museums have been repaired using traditional Japanese kimono sewing techniques, as a form of living heritage practice. This idea is based on Japan's cultural property preservation policy, which dictates that tangible cultural properties be inherited by intangible cultural property techniques. Not all Japanese historic textiles are preserved based on this thinking. It is applied only to designated cultural properties that have government involvement. From a global perspective, this way of thinking is unique as a cultural property protection policy and is an interesting example of how diverse cultural property protection is today. Throughout the world, there are varying ideas and methods for stitch reinforcement of textiles. It should be noted that the methods shown here represent those compiled in Europe and the United States where the author was educated and are different from the traditional stitches based on Japanese kimono sewing and embroidery techniques. See Chapter 5(p.241) for further disscussion.

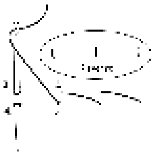
When a historic textile is proposed for conservation treatment, the first step is to carry out a thorough object examination. The manufacturing technique, its history and condition are investigated, and the significance/ extent of the damage is evaluated. The idea that "restoration of textiles is practised by needle and thread" prevailed for a long time, and reinforcement by stitching was considered a re-treatable method[2]. However, stitching does leave holes, and if the fibres are degraded they may be broken by the stitching, rather than stabilized and supported. Based on reviews of past restoration techniques, less interventive treatments are practised today, so as not to detract from the artefact's research value. When planning a conservation

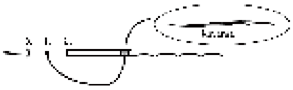
Examples of conservation stitches used in Europe and North America

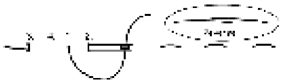

Running stitch


Stab stitch


Basting stitch

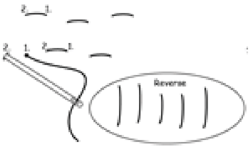

Diagonal basting stitch


Back stich


Half back stitch

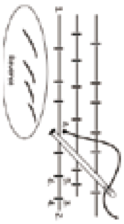

Running back stitch

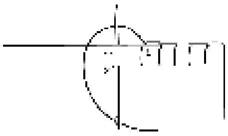

Tacking stitch

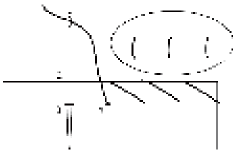


Staggard running stitch

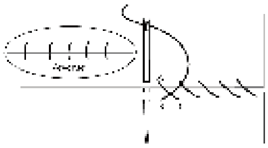

Herring-bone stitch

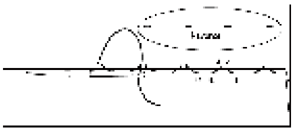

Laid thread and couching stitch


Blanket stitch


Whip stitch

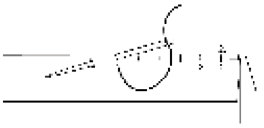

Cross stitch

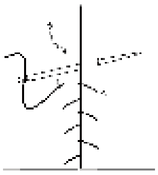

Over sewing stitch


Slip stitch


Reverse herring-bone stitch


Blind stitch


Overhand stitch


Lacing stitch

treatment, the first option to consider is reinforcement of the whole artefact without intervention (such as mounting). The next option is to stabilize with a needle and thread. Finally, adhesive treatments are considered, where fibres are impregnated. In all cases, the current role and use of the artefact should be considered.

1. The aim of stitching as used in supporting textiles

The stitching used in textile conservation embodies a function that is to "support the textile". Although stitching is also used as a method of decoration in embroidery and for joining and assembling in sewing, in conservation, the purpose of stitching is reinforcement[3-4].

2. Fabric support/reinforcement of textiles

Reinforcement or support of textiles can be broadly classified as full reinforcement (full support) or partial reinforcement (patch support). Full reinforcement is performed when the fabric has weakened overall, and a new cloth is appended to the whole of the under surface. In partial reinforcement, where the condition of the fibres is good, but partly damaged, new fabric is attached to the damaged area. A support fabric may be attached to the face of the textile, either as a patch or as a full support, or it may be used to sandwich the textile from either side. When the front face of the textile is covered, a semi-transparent fabric is often selected.

3. Selecting a fabric

A fabric is selected according to its compatibility with the textile by looking at aspects such as material content, quality, fibre spin, fabric structure, handle, elongation, weight, colour, colourfastness of the dye, flexibility, sheen, and finishing, etc. When supporting a textile from its reverse face, a fabric with similar fibre content and structure, but lighter and woven with a higher weave count, is often the choice. For fine textiles or for covering the front face of the textile, a semi-transparent plain weave silk (silk crepeline), a plain weave polyester (Stabilitex® Tetex®), or a nylon or polyester net may be used. Nylon is not a strong fibre when exposed to light but being a polyamide fibre, it can be dyed with the same dye as silk and wool, thus is frequently used along with polyester net. Fabrics must be washed and shrunk before use.

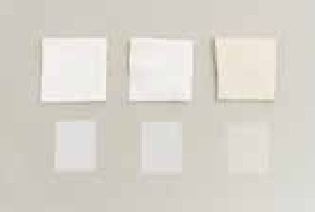


Fig. 23.5 Plain weave that has a stable structure is commonly used for support fabrics.

Fig. 23.6 Set up for stitch support.

3.1 Woven fabrics and weave count

Woven fabrics are constituted of warps and wefts. A weave count of a woven fabric is the number of warps or wefts per 1 cm or 1 inch (2.54 cm). Weave count can be determined either by placing a measure fabric on the fabric and counting the number of warps or wefts using a magnifying glass or utilizing a linen tester fitted with a lens and a scale having sides measuring 1 cm or 1 inch. In general, a woven fabric with a high density will have small gaps between yarns and a woven fabric with a low density will have large gaps between yarns. If the number of wefts is higher than the warps, the fabric will become hard, whereas if the number of wefts is lower than the warps, a soft fabric is obtained. In addition, even if the weave count is high, gaps may be present between the fine yarns. In the case of a fine yarn fabric with a low weave count, the yarns easily slip because of the large gaps, which make the fabric structure. Therefore, the thickness of the yarns and the weave density greatly affect the texture of a fabric, and the thickness, structure, and density of the fibres and yarns vary according to the intended use of a fabric. Therefore, when selecting a commercially available fabric for supporting a historic textile, it is necessary to first investigate the fibres, yarns, structure, and weave density of the artefact, and then select a fabric that is suitable for the required treatment. The material content of the artefact, fabric structure, severity of damage and degradation, and how the artefact is going to be handled and exhibited, such as horizontally placed in a case, vertically suspended on a wall, or draped on a mannequin, will dictate the choice of support fabric.

3.2 Preparation of support fabrics

Any sizing (starch etc.) should be removed from the fabric and rinsed with hot water to remove machine oil and soiling, pre-shrunk, and then ironed to align the weave. The fabric is left to acclimatize for at least a week before use.

Fibres are thermoplastic and it is essential to set an appropriate temperature when ironing the fabric. As synthetic fibres, such as nylon and polyester, are thermoplastic rather than hydro-plastic, creases are not able to be removed without ironing.

Table 23.1 Ironing temperature for fibres

Category	Fibre	Iron temperature（℃）
Natural cellulose	Cotton	160－ 180（high）
	Linen	180－ 200（high）
Natural protein	Silk	110－ 130（medium）
	Wool	110－ 150（medium）
Regenerated cellulose	Rayon	110－ 150（medium）
Modified regenerated cellulose	Acetate	110－ 130（low）
	Triacetate	
Synthetic	Nylon	
	Polyester	
	Acryl	
	Polyurethane	

4. Selecting threads

Fig. 23.7 Dyed filament thread for support stitching.

Fig. 23.8 Polyester threads.

A thread is selected according to its compatibility with the textile by looking at its fineness, material, twist, colour, elongation, flexibility etc. A thread will be abraded by the mechanical stress of passing through layers of fabric and then stitching thus it is better if it is twisted and plied. Filament silk is often used when a very fine thread is necessary, but in such a case, it is better to twist the thread between the palms of the hands and make a plied yarn, which is more stable. The material of the threads is often the same as the textile to be stitched but in cases when metal components need to be attached, polyester thread (Gütermann Skala®) is more susceptible to metal corrosion.

In selecting a sewing thread for the conservation of textiles, some conservators suggest using a "weaker" thread than the textile itself, or even a thread which has been purposely deteriorated. This is based on the idea of mitigating the damage which may be caused when a new thread encounters an embrittled fibre. Although this reasoning can be approved, there is a problem in using "weakness" as the selection criterion for the material. Reinforcement is performed to stabilize the textile, and the material should be long-lasting. With "weak" or already deteriorated materials, the duration of stabilization will become shorter. To extend the lifetime of the textile after treatment, and to mitigate the load of new material, materials should be selected following the criteria of "chemical stability", "softness", and "fineness". Opinions may differ among conservators as to the selection of restorative materials and the reasoning behind them.

4.1 Yarn thickness (fineness) and units

Fineness denotes the "thickness" of a yarn. Because the cross-section of yarn is not circular, this thickness is represented by the ratio between the "length" and "weight". The units expressing thickness differ depending on whether a fibre is a filament yarn or a spun yarn.

4.1.1 Tex

The thickness of yarn having a weight of 1 g per 1000 m length is called 1 tex.
1 dtex is one-tenth of 1 tex (10 dtex = 1 tex)[5].

4.1.2 D (denier)

The thickness of yarn having a weight of 1 g per 9000 m length is called 1 denier.

4.1.3 Count

"Count" is used for spun yarn by calculating the thickness of yarn based on a fixed weight. "Cotton count" is a measure whereby a yarn having a length of 840 yards per 1 pound (453.6 g) is a "No. 1 count", with the count number increasing as the yarn becomes finer. That is, the No. 1 count denotes a thick yarn, and the No. 100 count denotes a fine yarn. Yarn thickness calculations vary according to the type of fibre. In notational methods, a No. 60 count single-ply yarn is denoted as "1/60" and a No. 60 double-ply yarn is denoted as "2/60."

Low counts (thick yarn)

Cotton count: No. 20 count or lower; wool count: No. 36 count or higher; flax count: No. 40 count or lower; and ramie count: No. 25 count or lower.

Fine counts (fine yarn)

Cotton count: No. 60 count or lower; wool count: No. 72 count or higher; and flax count: No.100 count or lower.

Table 23.2 Count of spun yarn

Type	Unit	Length	Weight
Cotton count	S	768.1m (840Yd)	453.6g (1b)
Linen count	R	274.3m (300Yd)	453.6g (1b)
Metre (wool) count	Nm	1,000m	1,000g

4.2 Ultrafine yarns for conservation

4.2.1 Silk yarns

For ultrafine silk yarns used for conservation, yarns obtained by hand reeling immediately after cocoon formation are soft and exhibit good dyeability. Since sericin remains, it lacks lustre and has firmness. Refining at around 60°C in a warm alkaline bath (pH around 10) gives it lustre and softness.Yarns obtained by mechanical reeling from cocoons treated with hot air for insecticidal purposes and storage and dry and hard. Silk filament yarns used for conservation have a fineness of 10-25 denier. Such yarns can be used as filaments, but finely twisted yarns do not suffer from fluffing during stitching and last well. Silk yarns are dyed using acidic dyes or metal complex dyes.

4.2.2 Cotton yarns

Fine cotton yarns used for conservation have a fineness of No. 90-120 count. Cotton yarns are dyed using direct dyes or reactive dyes.

4.2.3 Polyester yarns

Polyester is less susceptible to acids and alkalis, and is often the choice for use with textiles containing metals such as iron, tin, and copper. German company Gütermann sells the ultrafine yarns Skala 360 (8 dtex) and Skala 240 (120 dtex) in many colours. Because polyester yarns are dyed with disperse dyes under pressure, brand-name goods are used because dyeing is not possible in conservation laboratories in museums.

5. Needles

The type of needle to be used is selected after deciding on the yarn to be used, basis on the fibres, structure and state of the historic textile being treated. The needle thickness is based on the centre of the needle, and the needle length is selected according to workability. As products are subject to industrial standards, needles are stipulated in terms of type and dimensions (thickness and length) according to the intended use and name. However, ultrafine needles used in textile conservation (for example, beading needles and embroidery needles) are special and do not have industrial specifications. Products made by major British manufacturers are high quality and include many types. In addition, Japanese hand-made needles for embroidery are very fine and have a smooth finish and are extremely high in quality.

Pins and needles used in textile conservation should be those which make puncture holes as small as possible, with a needle thickness of approximately 0.3- 0.5 mm. High-quality needles should have a sharp tip and a smooth finish. Beading needles, Sharps No. 12 and silk needles are often used as fine needles. Regarding needle lengths, a short needle is easier to sew with when using a sewing method where a textile is spread over a support fabric on a frame or over a table hole and one hand is placed on the top and the other hand on the bottom to send the needle up and down. However, a long needle is suitable in cases where the stitching is carried out on a table surface.

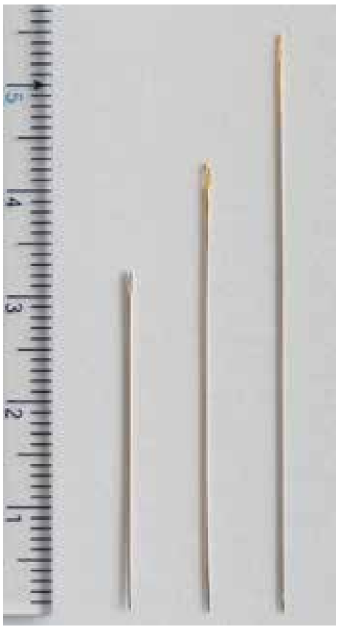


Fig. 23.9 Machine-made needles with varying fineness and length.

Fig. 23.10 Handmade extra fine needle (*Kebari*, Misuya Needles)

Fig. 23.11 Machine made fine needle (*Ohoboso*, Misuya Needle)

Table 23.3 Needle

Width (mm)	**Length (mm)**	**Maker or distributer**		
		Clover （Japan） https://clover.co.jp/product.html	**John James （U.K.）** https://www.jjneedles.com/	**Misuya Needles (Japan)** https://misuyabari.com/
0.2	24	-	-	Handmade needle (Edotsuke)
0.25	27	-	-	Handmade needle (Kebari)
0.25	45	-	Beading needle No.15	-
0.3	49	-	Beading needle No.13	-
0.35	27	-	-	Handmade needle (Gokuboso)
0.36	27.3	-	-	Embroidery needle (Ohoboso)
0.36	32.5	-	Short beading needle No.12	-
0.36	51	-	Beading needle No.12	-
0.40	27	-	-	Handmade needle (Ohoboso)
0.41	22.5	-	Quilting/Betweens No.12	-
0.41	29.5	-	Sharps No. 12 Embroidery No.12	
0.41	36.4	Beading needle (fine)	-	-
0.41	42.4	Beading needle No.16	-	-
0.41	48.5	Beading needle No.13	-	Beading needle
0.41	54.6	Beading needle No.10	-	-
0.41	51	-	Beading needle No. 11	-
0.46	25.4	Gold eye quilting needle between No.10	-	-
0.46	27.3	-	-	Embroidery needle (Tenboso)
0.46	28.8	Applique needle ≪ Sharps No.12 ≫	-	-
0.46	31	-	Sharps No. 11	-
0.46	32.5	-	Short beading needle No.10	-
0.46	33.3	French embroidery needle No. 10	-	-
0.46	39.4	Beading needle (fine)	-	-
0.46	55	-	Beading needle No.10	-
0.51	22.7	Quilting needle　No.12	-	Quilting needle No.12
0.51	27.3	-	-	Embroidery needle (Kanboso)
0.51	28.8	Silk needle No.13	-	Silk needle (Kinu)
0.51	36.4	-	-	Silk needle (Kinutsuma)
0.51	39.4	-	-	Silk needle (Kinukishi)
0.53	42.9	Curve needle (fine)	-	-
0.53	66	-	Curved beading needle No.10	-
0.76	-	-	Curved tapestry needle No.24	-
0.86	44.5	Curve needle t(hick)	-	-

Fig. 23.12 Curved needles

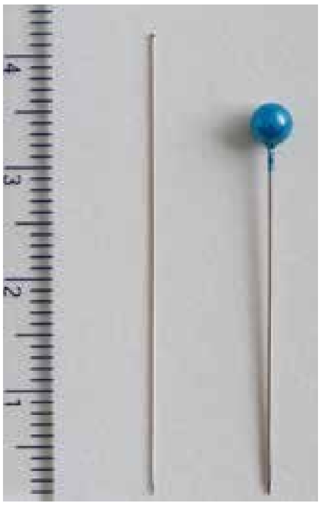


Fig. 23.13 Stainless steel entomology pin and stainless steel dressmaker pin.

Table 23.4 Stainless steel pins

No.	Width (mm)	Length (mm)	Maker or distributer
000	0.25	38	Entomoravia (Czech Republic) Austerlitz insect pins ® https://entomoravia.eu/index.php/2-uncategorised/1-austerlitz-insect-pins Morpho® (Czech Republic) Sphinx® (USA) Shiga Ethomology（length 40 mm） http://www.shigakon.com/
00	0.3	38	
0	0.35	38	
1	0.4	38	
2	0.45	38	
3	0.5	38	
4	0.55	38	
5	0.6	38	
6	0.65	38	
7	0.7	52	

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24 Adhesive support

1. Evaluation of adhesives

Natural-based adhesives such as starch paste and animal glue have traditionally been used to bond textiles with other materials such as paper or wooden boards. However, in textile conservation in Europe and North America, the use of natural-based adhesives is not widespread compared with synthetic adhesives because starch and gelatine can become a food source for insects, and starch can only be removed with enzymes. They also need to be applied wet onto the fibres, causing swelling and shrinkage after drying, and hardening the fibres. In Japan, starch paste has traditionally been used as a repair material in the restoration of Japanese paintings on silk and paper works. Because the preparation and application of starch paste requires a skilled technique and is therefore difficult for a textile conservator trained in sewing techniques to carry out this practice, starch paste technique on textiles is usually carried out in collaboration with a paper conservator[1.]

In the mid-1950s, chemical treatments using synthetic adhesives such as polyvinyl alcohol[2] and poly butyl methacrylate[3] appeared in the conservation of textiles. In the 1970s, despite questions already being raised about the use of soluble nylon in the field of conservation, it was applied to ancient Egyptian linen tunics to strengthen the fibres[4]. However, there were reports against the use of soluble nylon from that time[5]. Today, aged nylon cannot be removed from ancient linen. Case studies such as this remind us of the importance of making informed decisions based on scientific study in conservation.

Chemical reinforcement of textiles using synthetic adhesives have been applied when a stitching technique is inappropriate because of the degraded nature of the fibre or because of the fabrication method of the artefact. Examples of use include archaeological textiles, tin weighted silks, iron mordanted textiles, painted cloth, bark fibre, synthetic materials, leather materials, and three-dimensional objects. A survey on the kind of adhesives used among textile conservators was carried out in 1997 and adhesives commonly used in textile conservation were evaluated[6-7].

Notable scientific tests on the long-term application of adhesives, including those used in textile conservation, are by Howells et al.[8] who studied PVA polymer dispersions, Feller et al.[9] who evaluated cellulose ethers (Table 24.1), Hornton-James et al.[10] who tested several polymers for flaking paint and concluded that the best results were observed in Plextol B 500 and Primal AC33, and Down et al[.11] who evaluated a large number of polyvinyl and acrylic type polymers (Table 24.2). Horie revised his 1986 edition of *Materials for Conservation: Organic Consolidants, Adhesives and Coatings* in 2010 with updated information[12].

Over the 60 years since synthetic adhesives were first introduced in conservation, many case studies have been reviewed, and problems such as hardening, discolouration, non-re-treatability or contamination have been reported. When using adhesives, information such as product information, recent research reports on the long-term stability of the product, case studies, and consideration of its effects on future scientific studies need to be considered. Adhesives should not be casually applied to historic textiles, and they should be used only as a last resort when no other methods for stabilization are available. It is not a treatment technique to be used to save time.

Table 24.1 List of cellulose ethers that performed well in the accelerated ageing tests carried out at the Getty Conservation Institute[13]

Polymer	Examples of product names
MC	Culminal™ MC2000
HPMC	Methocel™ E4M
SCMC	Gabrosa® P200G, Cellofas B3500
EHEC	Bermocoll® E 481 FQ, Ethulose
HPC	Klucel G
HPC	Klucel E

Table 24.1 Notations: MC= methyl cellulose, HPMC= hydroxy propyl methyl cellulose, SCMC=sodium carboxy methyl cellulose, EHEC=ethyl hydroxy ethyl cellulose, HPC= hydroxy propyl cellulose
The table is listed in descending order of long-term stability from top to bottom.
Ethyl cellulose (EC), ethyl hydroxyl ethyl cellulose (OS-EHEC) that dissolves in organic solvents, and hydroxyl ethyl cellulose (HEC) are not suitable for long-term use in artworks.

Table 24.2 List of PVAC and acrylic adhesives that performed well after accelerated ageing tests carried out by the Canadian Conservation Institute[14]

Main polymer	Product name
PVAC homopolymer + Multiwax #445	Rabin's mixture
PVAC + soap + polyacrylamide	Jade 403 Replaced by Jade 403N
PVAC + soap +polyethylene glycol dibenzoate	R-2258
PVAC + soap + unidentified minor components	Elvace® 1874 (discontinued) Replaced by Elvace® 45675 (not tested)
EVA ＋ ketone resin N (polycyclohexanone) + paraffin + phthalate (ester of hydroabietyl alcohol)	Beva® 371
PVAC maleate copolymer + soap + methyl cellulose	Mowilith® DMC2 (discontinued)
PBA	Rhoplex™ (Primal™) N580
PEMA	Elvacite® (Paraloid®) 2028
PBMA	Acryloid® (Paraloid®)F10
PiBMA	Acryloid® (Paraloid®) B67
PMA/PEMA	Acryloid® (Paraloid®)B72
66%P EA + PMMA	Rhoplex™ (Primal™) AC33 Replaced by Rhoplex™ (Primal™) B60A (not tested)
66% PEA + PMMA	Rhoplex™ (Primal™)AC234
50% PEA + PMMA	Acryloid ®(Paraloid®) B82
<50% PEA + PMMA	Acryloid®(Paraloid®) B44S
PBA/PiBA	Rhoplex™ (Primal™)N619
20-40% PBA + PMMA	Acryloid® (Paraloid®) B48S
56% PBA + PMMA	Rhoplex™ (Primal™)AC235
>50% PBA +PMMA	Lascaux® 360 HV（discontinued） Replaced by Lascaux® 303HV (not tested)

>>50% PBA + PMMA	Rhoplex (Primal)N560
PBA + acrylonitrile	Rhoplex (Primal)N1031
PMMA + PMA+ stylene	Acryloid (Paraloid) B99
PMA + PiBMA + unidentified minor components	Acryloid (Paraloid) NAD10

Notations: PVAL=poly vinyl alcohol, PVAC= poly vinyl acetate, PBA=poly butyl acrylate, PBMA=poly butyl methacrylate, PEMA=poly ethyl methacrylate, PiBA=poly isobutyl acrylate, PiBMA=poly isobutyl methacrylate, PMA= poly methyl acrylate, PMMA=poly methyl methacrylate

2. Criteria for selecting adhesives for textile conservation

An ideal adhesive should be safe and easy to handle, have low viscosity to ensure good penetration, exhibit minimal shrinkage due to solvent loss, and should not swell fibres. It should provide strength, and in some cases, flexibility, to degraded and embrittled fibres, remain reversible and chemically stable over a long period, and should not change the colour, texture or appearance of the fibre. There are two main criteria for an ideal adhesive. 1) properties necessary at the time of application, 2) properties necessary over a long period of time. Practical factors determining the choice of synthetic adhesives are listed below[15].

① Long chain polymers (DP=degree of polymerization); Longer chains result in a film consisting of better mechanical properties than polymers with a short chain.
② Mechanical properties; including film-forming properties, peeling strength and flexibility.
③ Acid and alkali (pH); A neutral pH is required because pH-sensitive dyes and fibres may deteriorate.
④ Heat conditions; above Tg (=glass transition temperature) the polymer becomes elastic and sticky.
⑤ Solvent (plasticizers) conditions; The presence of a solvent decreases the Tg. The Tg of a solvent adhesive is at its lowest at the beginning of the solvent evapouration process (hardening). Under conditions of high humidity, water, acting as a plasticizer, softens the adhesive and creates an isolating layer between the textile and adhesive film.
⑥ Long-term chemical stability.

Table 24.3 Adhesives used in textile conservation

Type	Product name	CAS No.	Chemical composition	Viscosity cps	T g ℃	Solvent	Note
Cellulose ethers	Gabrosa™P200G	9000-11-7	Sodium carboxymethyl cellulose (SCMC)	50-200 (4%, 25℃)	-	Water	Suspending agent in adhesives.
	Cellofas B-3500			3,500	-		
	Cluminal™MC2000 (Hercules)	9004-67-5	Methyl cellulose (MC)	2000 (2%, 20℃)	-	Water	Adhesive and suspending agent.
	Methocel™A4C (Dow)			4,000	-		
	Beromocoll®E 481 FQ (Akzo Nobel)	9004-58-4	Ethyl hydroxyethyl cellulose (EHEC)	4,250-6,000 (1%, 20℃)	-	Water、ethanol	Adhesive dry film support and consolidant for textiles and leathers.
	Ethulose				-		
	Klucel G (Hercules)	9004-64-2	Hydroxypropyl cellulose (HPC)	150-400 (2%, 20℃)	-	Water, ethanol, methanol, IMS, isopropanol	Adhesive dry film support and consolidant for textiles and leathers.
	Klucel E (Hercules)			200-600 (2%, 20℃)	-		
Acrylic resin, thermoplastic	Paraloid® B72 (Röhm & Hass)	97-63-2 96-33-2	70% ethyl methacrylate 30% methyl acrylate	-	40	n-butanol, acetone, ethanol, ethyl acetate, toluene, xylene	Adhesive and consolidant.
	Paraloid® B67 (Röhm & Hass)	53801-42-6	Iso-butyl methacrylate polymer.	-	50		
Acrylic colloidal dispersions, thermoplastic	Lascaux® 303HV (360HV discontinued) (Lascaux)	-	Aqueous dispersion > 50% n-butyl methacrylate other acrylate	5,000-10,000	-8	Water thin- able pre-dry- ing ethanol, Acetone, toluene	Adhesive dry film support and consolidant for textiles and leather.
	Lascaux® 498HV (Lascaux)	-	Aqueous dispersion > 50% n-butyl methacrylate other acrylate	7,000	13		
	Plextol™B 500 (Synthomer)	1336-21-6	Aqueous dispersion 60 % ethyl acrylate 40%methyl methacrylate Unidentified amount of ethyl methacrylate	100– 20,000 (20℃)	9	Water, ethanol	Adhesive and consolidant. pH 9.5
	Primal™(Rhoplex™) AC 33 (Röhm & Hass)	99550-83-1	Aqueous dispersion 60% ethyl acrylate 40% methyl methacrylate Unidentified amount of ethyl methacrylate	-	16	Water, ethanol	Adhesive and consolidant. pH 9.4-9.9
	Primal™ (Rhoplex™) WS24 (Röhm & Hass)	99550-83-1	Acrylic aqueous dispersion	600,000	39	Water, ethanol	Adhesive and consolidant for bone. Alkali soluble. pH 6.8-7.2
Poly vinyl acetate, thermo- plastic	Jade 403 replaced by 403N (Jade Adhesives)	-	Aqueous dispersion Poly vinyl acetate Poly vinyl alcohol	6,000-7,000	-	Water, ethanol	Adhesive and consolidant.
	Mowilith® DMC2 (Lascaux) Discontinued	-	Aqueous dispersion 65% vinyl acetate 35% dibutyl maleate	5,000-12,000	11	Water, ethanol	Adhesive dry film support for textiles and leather. pH 4.5
	Vinamal® 3253 (Vinyl Products)	-	Aqueous dispersion 50% ethylene 50% vinyl acetate	-	3	Water, ethanol	Adhesive dry film support for textiles and leather.
Polyethylene vinyl acetate, thermoplastic	Beva® 371 (Film and gel)	-	Polyethylene vinyl acetate	-	65-70	Ethanol, acetone, benzyne	Adhesive and consolidant.

3. Application techniques

There are two methods of applying adhesives to fibres: consolidation by liquid and adhesive support by application of a dry film that is re-activated. Once adhesive is introduced into the fibre, retreatment options will be limited to the same type of material and methods, thus future options for conservation of the artefact are narrowed. The presence of an adhesive may interfere with future scientific analysis. As conservation methodology and analytical instruments advance, so does our perspective towards conservation principles. Therefore, it is important to consider how to preserve an artefact's authenticity, without adding new conservation materials, leaving it safely intact for future generations.

3.1 Adhesion method: adhesive dry/reactivation method (dry film)

Adhesive dry film support began in England in the 1960s. A liquid adhesive is typically applied with a brush or roller to a thin piece of support fabric and dried to form a dry film[16]. The film is applied to the textile, and the adhesive is reactivated with an iron, in the case of a thermoplastic type, or with a solvent in the case of a solvent-plastic type. The dry film is pressed to reinforce it. The adhesive adheres to the surface of the fiber, and the amount of impregnation inside the fiber is small compared with liquid application. Once adhesive reinforcement is complete, it is necessary to store and display the items so that they are not moved as little as possible.

Viscosity is expressed as cPs (centipoises(s)=1/100 poise). In general, the larger the cps number, the greater the viscosity. With the same concentration, the differences in cps will result in different viscosity of the liquid.

3.2 Consolidation method: liquid impregnation method

Consolidation is a method in which natural or synthetic adhesives are introduced in their liquid state into fibres so that they become coated and impregnated. When solidified, the small fragments remain joined together with the resin. Even if using a resin that can be dissolved over time, this is considered a last resort option because the fibres will come apart if separation is attempted. Non-intrusive, stabilizing storage methods, such as mounting, are recommended before attempting coagulation with resin.

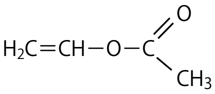
3.3 Reversibility and removability of the adhesive

Although both the liquid impregnation method and the drying/reactivation method theoretically assume the use of a long-term stable and reversible adhesive, there is a difference in the permeability of the adhesive. The adhesive is difficult to remove completely and remains on the textile. Therefore, reversibility in adhesive support means the ability to peel off and remove the adhesive film from the textile while swelling the adhesive with a solvent or applying heat. It is desirable to choose such an adhesive and take the optimum method.

4. Examples of synthetic adhesives used in textile conservation

4.1 Polyvinyl acetate (PVAC) (Liquid application, water-soluble, dry film application, thermoplastic, reactivation.)

Polyvinyl acetate $(C_4H_6O_2)n$ is prepared by polymerization of vinyl acetate monomer. The ester group of vinyl acetate is sensitive to alkali and will slowly convert PVAC to polyvinyl alcohol and acetic acid. It is water soluble and thermoplastic. Mowilith DMC2 has been used in treatments of ancient Egyptian textiles[17-18]. Despite its use in the 1960-90s, due to its negative long-term stability, it is less used in textile conservation today. Product name: Jade 403/403N (pH 7.1-7.3), Mowilith® DMC2, Vinamul® 3252.



$H_2C{=}CH{-}O{-}C({=}O){-}CH_3$

Vinyl acetate

4.2 Ethylene vinyl acetate (EVA) (Liquid application, organic soluble, dry film application, thermoplastic.)

Ethylene-vinyl acetate is a copolymer of ethylene and vinyl acetate and has flexibility and elasticity. Beva® 371 was developed in 1970 and has been used in conservation with modifications. It is sold in gel and film form. It is thermoplastic and the gel melts at 50-55℃ and the film at 65 -75℃ and should be used at around 65℃. It is soluble in naphthalene, benzene, toluene, acetone, and alcohol. It is used in leather conservation[19]. Product name: Beva® 371.

4.3 Poly butyl methacrylate (Liquid application, water-soluble, dry film application, thermoplastic, reactivation.)

Butyl methacrylate $(C_8H_{14}O_2)n$ is a dispersion of acrylic polymer based on methyl methacrylate and butyl acrylate. Product name: Lascaux® 360HV/303HV, Tg = -8 ℃, dry film sticky, minimum sealing temperature (+50℃). Lascaux® 498HV, Tg = 13℃, elastic hard film, minimum sealing temperature (+68-76℃). Lascaux® 360HV/303HV and 498HV are often used in the ratio of 1:1 or 1:2 (v/v) to produce the required film properties for support treatments. Both are pH 8-9, dilutable with water during the application, soluble in acetone, and toluene, and insoluble in water and white spirits after drying[20-22.]

4.4 Methylcellulose (MC) (Liquid application, water-soluble)

Methylcellulose $(CH_3)n$ is a chemical compound derived from cellulose. It is synthetically produced by heating cellulose with a caustic solution and treating it with methyl chloride. The hydroxyl residues (—OH) are replaced by methyl ether linkage ($—OCH_3$). The white powder is water soluble but tends to form a gluey layer when in contact with water. When preparing a solution of MC, first mix the powder with hot water so that the MC disperses in the solution and let it cool down while stirring. The adhesion is not strong thus it is more used as a suspending agent with other adhesives. The first case study of the use of a cellulosic adhesive was on an Egyptian Coptic tunic that appeared in 1961[23]. Product name: Culminal™ MC2000 (Hercules), Tylose® MH (BmbH & Co.) and Metolose®(Shin Etsu Chemical).

4.5 Sodium carboxymethyl cellulose (SCMC) (Liquid application, water-soluble, reactivation.)

Carboxymethyl cellulose $(—CH_2CO_2H)n$ is also a cellulose derivative with carboxyl groups ($—CH_2COOH$). It is synthetically produced by the alkali-catalysed reaction of cellulose with chloroacetic acid. The adhesion is not strong thus it is more used as a suspending agent with other adhesives.

4.6 Hydroxypropyl cellulose (HPC) (Liquid application, water and solvent-soluble, dry film application, reactivation.)

Hydroxypropyl cellulose is an ether of cellulose in which some of the hydroxyl groups in the repeating glucose unit have been hydroxy propylated ($—OCH_2CH(OH)CH_3$). Thus, the polymer has both hydrophilic and hydrophobic groups which means that it is soluble in both water and organic solvents. Product name: Klucel (Hercules) adhesives (E, L, J, G, M and H) are non-ionic cellulose ethers, soluble below 38℃, insoluble above 40℃, soluble in methyl alcohol, ethyl alcohol, isopropyl alcohol (95%) and insoluble in toluene, xylene, trichloroethylene. It is highly surface active and highly flexible. pH 5.0-8.5 in 1.5% water. At 4% it becomes a viscous liquid, and at 8-10% a gel. Case studies on reactivating the polymer film with organic solvent have been reported[24].

4.7 Ethyl hydroxyethyl cellulose (EHEC) (Liquid application, water and alcohol soluble, dry film application, reactivation.)

Ethyl hydroxyethyl cellulose is cellulose in which both ethyl and hydroxyethyl groups are attached to the anhydro glucose units by ether linkages. Ethyl hydroxyethyl cellulose is prepared from cellulose by treatment with alkali, ethylene oxide and ethyl chloride. The chemical formula is $[C_6H_7O_2(OH)_x(OC_2H_5)_y[O(CH_2CH_2O)mH]_z]_n$. Product name: Bermocoll® E 481 FQ, pH 7.0 in 1% water. At 4% it becomes a viscous liquid, and at 8-10% a gel. It has been used as a consolidant for flaking paint[25].


Fig. 24.1 Spray the table with water.


Fig. 24.2 Lay down the casting sheet.


Fig. 24.3 Wipe the water around the sheet and secure it with masking tape.


Fig. 24.4 The thickness of the adhesive film is adjusted by layering masking tape, and the adhesive is stretched with a glass rod.

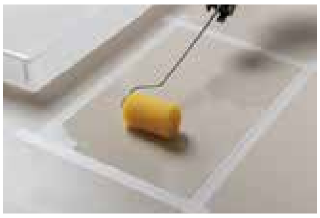


Fig. 24.5 Create an adhesive film with a sponge roller.

Practice 1

Understanding adhesive properties and application evaluation

The given concentration of adhesive is only for comparison for this practice and is not a recommended value for conservation treatments. It is important to learn about the results of using these adhesives on textiles and how they serve the conservation and restorative purpose of long-term stabilization.

1. Preparation of adhesives

(1) Sodium carboxy methyl cellulose (SCMC)
① 5% w/v Culminal™ MC2000 (cps 2,000) in water

(2) Methylcellulose (MC)
② 5% w/v Culminal® MC2000 (cps (2,000) in water
③ 5% w/v Methocel™ A4C (cps 4,000) in water

(3) Ethyl hydroxyethyl cellulose (EHEC)
④ 5% w/v Bermocoll® E 481 EQ (cps 4,250-6,000) in water

(4) Hydroxypropyl cellulose (HPC)
⑤ 5% w/v Klucel G (cps 150-400) in water
⑥ 5% w/v Klucel E (cps 4,000) in water

(5) Poly butyl methacrylate + poly methyl methacrylate (PBA + PMMA)
⑦ Lascaux® 303 HV full strength (cps 5,000-7,000)
⑧ Lascaux® 498HV full strength (cps 7,000)
⑨ 10 % w/v Lascaux® 303HV : 498HV= 1:1 (v/v) in water
⑩ 10% w/v Lascaux® 303HV : 498HV= 1:2 (v/v) in water

(6) Polyvinyl acetate (PVAC)
⑪ Jade 403 full strength (cps 6,000-7,000)
⑫ 10% w/v Jade 403 in water

(7) Ethylene vinyl acetate (EVA)
⑬ Beva® 371 gel
⑭ Beva® 371 film(2.5 μm)

(8) Acrylic resin
⑮ 10% w/v Paraloid® B72 (PMA/ PEMA) in acetone
⑯ 10% w/v Paraloid® B67 (PiBMA) in acetone

Fig. 24.6 Secure silk crepeline onto the casting sheet.

Fig. 24.7 Secure on two sides so that the fabric can be alined.

Fig. 24.8 Apply the adhesive with a sponge roller.

Fig. 24.9 Apply the adhesive with a glass rod.

Fig. 24.10 Try out other materials such as Japanese paper and non-woven fabrics.

Fig. 24.11 A heated spatular is used to reactivate adhesives with heat.

2. Tools and equipment

Support materials: silk crepeline (Talas U.S.A.), nylon or polyester net, non-woven polyester, fine polyester plain weave fabric (Stabiltex®), fine Japanese paper (machine-made Kozo paper RK-0, RK-00, RK1, Paper Nao, Tokyo)

Casting material: polyester clear sheet (Mylar®, Melinex®), thick polyethylene sheet,

Adhesive application tools: brush, roller sponge, glass rod, spray bottle (for adhesive)

Reactivation tools: dry iron, heat spatula, distilled or de-ionized water, ethanol, acetone

Others: masking tape, acrylic sheet, weights, tweezers, water resist pen, wiper, labels, silicon release paper, spray bottle (for water)

3. Liquid application(consolidation)

1. Place a practice textile onto a piece of clear polyester sheet.
2. Apply adhesive in the liquid state with different tools.

4. Dry application (preparation of dry films)

4.1 Casting dry films

1. Secure a piece of clear polyester or clear polyethylene sheet to the tabletop with masking tape. This is the casting base. Experiment with different casting bases. Mylar®(polyester) may not be the best choice for some adhesives, as they will stick to and pull away from the fabric in favour of adhering to the mylar. A polyethylene sheet is a better choice for acrylic colloidal dispersions, such as Lascaux® 303HV and 498 HV.
2. Evenly apply adhesives onto the casting base to produce dry films.
3. Note the adhesive type, number of coats and tools used.

4.2 Casting adhesive onto support materials (silk crepeline, Japanese paper, nylon net, non-woven polyester etc.)

1. Place a support material onto a polyester or polyethylene sheet. Experiment with different casting bases and support materials.
2. Moisten the support fabric with filtered or de-ionised water. Align the weave.
3. Evenly apply adhesive to the support fabric.
4. Note the adhesive type, number of coats and tools used.

4.3 Application to textiles

Apply adhesive support to a practice textile, either by reactivating the adhesive with solvents or heat application, depending on the type of adhesive. Evaluate methods of application, effectiveness as a support technique, colour change of textile, flexibility etc.

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25 Dyeing with Synthetic Dyes

In textile conservation, fabrics and threads used for support stitching and display are dyed to a required colour. This chapter explains the method of dyeing fibres using synthetic dyes.

1. Dyes used in textile conservation

Since the Englishman William Perkin (1838-1907) invented aniline dye from coal tar in 1856, synthetic dyes, which allow for easy colour matching, have been used for the conservation of historic textiles. For example, the lower edge of the famous 15th-century tapestry, The Lady and the Unicorn, in France's National Museum of the Middle Ages (Cluny Museum) was restored in 1894, using aniline-dyed yarns. Today, the synthetic colour has faded, and the overall appearance of the tapestry has been affected. The original natural dyes of the tapestry such as madder and indigo are still preserved. Such a case study tells us that materials, including dyes, used for conservation treatments should be long-lasting.

Various kinds of durable synthetic dyes were developed after the 1950s and were used alongside natural dyes. However, the current protocol for the conservation of museum artefacts states that: "All alterations should be distinguishable from the original object or specimen"[1]. According to this guideline, since natural dyes make future scientific identification confusing, colour matching difficult and do not satisfy the same durability criteria as current synthetic dyes, in textile conservation synthetic dyes are generally used.

≪ Requirements for dyes used in textile conservation ≫[2]

1. Dyes must be resistant to light (not easily faded by light).
2. Dyes must be resistant to washing (no colour running with water).
3. After dyeing reagents must not remain as they will damage the fabric.
4. Dyes must offer a wide range of colours, light and dark, and must have colour reproducibility.
5. They must make dyeing safe, easy, and economical.

Dye fastness is a tested value of the resistance of a dyed fabric to water, light and friction. The higher the value achieved indicates the better performance of the dye. In the case of historic textiles, support fabric and thread dyed for conservation expect to be illuminated within a museum environment but are not expected to be washed repeatedly. Therefore, a dye should be chosen based on its light fastness. Testing methods of light fastness of dyed fabrics are specified by the International Standardization Organization (ISO 105-B02), the American Association for Textile Chemists and Colourists (AATCC Test Method 16-2004), and Japanese Industrial Standards (JIS L 0842). All use the blue wool standard as an index of colour fading and are compatible. On the blue wool standard, 1 is the lowest and 8 is the highest. Dyes used for textile conservation should have an index of 5 or higher[3].

Table 25.1 Synthetic dyes used in textile conservation

Fibre	Brand	Type	Manufacturer
Cellulosics Cotton	Solophenyl®	Direct dye	Huntsman (Ciba-Geigy)
	Sirius®	Direct dye	DyStar (Bayer, Hoechst, Mitsubishi)
	Levafix® Remazol®	Reactive dye	
Proteins, polyamides Wool Silk Nylon	Irgalan®	1:2 metal complex acid dye	Current manufacturer unknown. (Ciba-Geigy)
	Lanaset®	1:2 metal complex acid dye and reactive dye	Huntsman (Ciba-Geigy)

(previous manufacturer)

From the 1950s onwards, and especially in Germany, durable chemical dyes started to be manufactured. One example is that of Ciba Speciality Chemicals, Geigy Company. Ciba-Geigy obtained a patent in 1952 for Irgalan®, an acid dye which had long been used in textile conservation. Now that the patent rights have been lost numerous manufacturers have become involved. The US company Huntsman, which acquired Ciba-Geigy, no longer handles this product. For this reason, there are some dyes for which product data cannot be obtained. For dyes used for textile conservation, it is desirable to have products for which durability tests have been published.

A textile conservator dyes cotton or silk, which are natural fibres, depending on the textile to be treated. Synthetic fibres such as polyester, must be dyed at a high temperature of over 100°C. If no equipment is available, this task is entrusted to a dyeing contractor. When dyeing is contracted out, and not only in the case of synthetic fibres, either the dye used and its durability should be confirmed, or the dye used should be specified. Finishing such as starching is not required. Also, to avoid colour running, the fabric should be thoroughly rinsed with warm water before use to remove any surplus dye.

Table 25.1 shows the main synthetic dyes used in textile conservation. The German chemical companies Bayer and Hoechst teamed up with the Japanese company Mitsubishi in 1995 to establish DyStar. Ciba Specialty Chemicals & Geigy were acquired by the US company Huntsman in 2003. Therefore, some companies continue to make the same dyes and auxiliary agents as the old manufacturers, while some products have changed their names, and some products have been discontinued altogether. There are still old products and substitute products on the market. In this text, old names and current names of products are noted where possible. A list of dye manufacturers and resellers can be found at the end of this chapter.

The benefit of synthetic dyes is that the desired colour can be reproduced by careful attention to the amount of fibres, dyes, auxiliary agents, and the temperature, time, and acidity specified for each dye.

2. Types of dyes, auxiliary agents, and dyeing mechanisms

The temperature at which a dye easily binds to fibres (optimal dyeing temperature) is different for each dye. Temperature is raised slowly at the start of the dye cycle so that dyes that react in low temperatures will fix to the fibres. With the rising of the temperature, dyes with an affinity to high temperatures start to bind to the fibres. There are also dyes where the bonds break at high temperatures, and so for these dyes, the temperature is lowered in the second half of the dye cycle, at which point the dyes re-fix to the fibres.

2.1 Direct dyes[4]

Solophenyl® and Sirius® are direct dyes. They dissolve in water, and when heated, bind to cellulose fibres via hydrogen bonds and van der Waals forces (cohesive forces between neutral atoms with no electrons and between molecules). Their main chemical structure is a planar molecule with groups such as naphthol, azo, stilbene, phthalocyanine, and heterocycles. It is a relatively large, flat molecule with a sulfonic acid group (—SO_3H), a nitro group (—NO_2), and an azo group (—N=N—), as its main chemical structure.

hydrogen bond
Cellulose fibre -O -------- H-N-Dye-SO_3^-

An electrolyte (that dissolves in water to release ions, such as Glauber's salt-sodium sulphate, Na_2SO_4) is used as an auxiliary agent together with a levelling agent specified by the manufacturer[5].

2.2 Acid dye (anionic)[6]

Irgalan® and Lanaset® are anionic acid dyes which bond ionically to the amino groups of protein fibres. Dyeing takes place under weakly acidic (pH 4-5) to neutral conditions, because the amino group of the protein fibres is cationic, and the dye which ionizes to anions in water forms a salt linkage.

In addition, the dye and the fibres bond together by hydrogen bonds, dipole-dipole bonds and van der Waals forces. Irgalan is a 1: 2 type metal complex dye among acid dyes. One metal (Cr^{3+} Co^{3+}, etc.) atom is coordinated between two dye matrix molecules with sulfonic acid groups[7]. Lanaset® is a 1:2 mixture of a 1:2 type metal complex acid dye and Lanasol®, which is a reactive dye[8]. A reactive dye has active groups which react with hydroxyl groups or amino groups in fibres to fix the dye by covalent bonding. It is therefore a durable dye which forms a stable bond between the fibres and the dye.

2.3 Reactive dye

Levafix® and Remazol® are reactive dyes. The dyes have reactive groups such as dichlorotriazinyl and when cellulosic fibres are dyed in an alkaline solution, the molecules form ether bonds (—O—) with the hydroxyl groups (—OH) of the fibre and form covalent bonds. Thus, the colour becomes fast to light and washing but is not strongly resistant to abrasion. The British company I.C.I. industrialized it in 1956. It is suitable for dyeing cellulosic fibres.

The type of dye molecule and the reaction temperature are interrelated, and the dyes may be classified into three groups; high-reactive low-temperature types (40-50 ℃ dichlorotriazinyl), middle-reactive middle-temperature types (60 ℃ vinyl sulphonate, vinyl amide) and low-reactive high-temperature types (70-90 ℃ monochlorotriazinyl). Reactive dyes made for wool fibres are acid sulphonate types and are used to dye polyamide fibres such as wool, silk and nylon. In conservation, middle reactive types such as Levafix® and Remazol® are used to dye paper. There are various methods of dyeing, but the most practised method is to let the fibre absorb the dye in a neutral pH dye bath and then immerse the fibre in an alkaline solution, whilst raising the temperature, to encourage chemical reactions (two-bath method). Lanaset dye® contains a reactive dye for wool Lanasol® (Huntsman) and metal complex acid dye at a 1:2 ratio. Therefore, it can be dyed in a neutral pH dye bath but due to the dye mixture, it may result in uneven dyeing.

Fig. 25.1 Auxiliary agents: retarding agent (left) and levelling agent(right)

2.4 Auxiliary agents

Auxiliary agents are added to the dye bath to achieve level dyeing.

2.4.1 Wetting agent

Wetting agents are surfactants which help to wet out the fibre to the core.

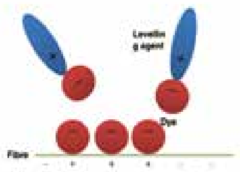


Fig. 25.2 Cationic levelling agent

2.4.2 Levelling agents

Levelling agents, which are often surfactants, help the fibre to absorb the dye evenly by attaching to the fibre or dye adjusting the speed of dye uptake.

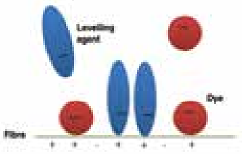


Fig. 25.3 Anionic levelling agent

2.4.3 Retarding agent

Glauber's salt, or sodium sulphate + hydrate (Na_2SO_4•$10H_2O$), is a retarding agent which controls the fixing of the dye to fibres and prevents colour unevenness[5]. Glauber's salt is a crystal hydrate of which approximately 50% is water. When sodium sulphate is heated in water, it dissolves in proportion to the temperature up to 32.38℃. When this temperature is reached it starts to decompose, forming crystals (Na_2SO_4+H_2O) and separating from the water. The crystals of sodium sulphate act like a masking tape to attenuate the repulsion between the fibres and the reactive groups in the dye which have the same polarity. At the same time, when the water temperature (energy load) is raised, the fibres and the dye bind together more readily, and the sodium sulphate separates out.

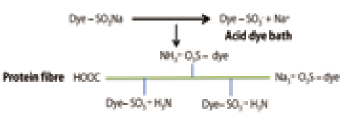


Fig. 25.4 Reaction of sodium sulphate as a retarding agent.

The amount of sodium sulphate to be added is calculated relative to the total water volume of the dye bath. This volume is noted later for each dye.

2.4.4 Accelerating agent

Accelerating agents are used for increasing the amount and speed of the dye uptake of the fibre. Neutral salts and acids are such chemicals.

3. Reading of dye labels

The dye label shows the brand name, colour and symbol. In dyes, there are no pure primary colours red, blue, or yellow. Dyes contain at least 2 other colours to the basic colour[9]. A dye marked as Red B, which is a red dye contains blue as a mixture, and Red 5B contains more blue dye. That is, Red 5B is a red colour with a stronger hue of blue (purplish red) than Red B.

3.1 Concentration of dye powder

If the concentration of a dye is not marked, it is assumed to be 100%. If different, it is marked as 200% (double concentration), 250% or 137% etc.

e.g.	Lanaset®	Red	2B
	Product name	Colour	Figure

This product is a Lanaset® dye, and from the brand information and label, we can tell that it is an acid dye for protein fibres. The colour is red, the hue is blue and the concentration is 100 %.

e.g.	Solophenyl®	Blue	GL	250 %
	Product name	Colour	Figure	Concentration

This product is a Solophenyl® dye and from the brand information and label, we can tell that it is a direct dye for cellulose fibres. The colour is blue, the hue is green, it is a light-fast dye, and the concentration is 250 %.

Table 25.2 Dye label symbols
(Lanaset® and Solophenyl®, Huntsman)

Symbol	English
B Bl	Bluer
G	Greener
R	Redder
Bn	Browner
Br	Brighter
De	Deeper
D	Duller
L	Lightfast
N	New dye
Conc	Concentration


Fig. 25.5 Mess cylinder and pipets.


Fig. 25.6 Measure the dye.


Fig. 25.7 Dissolve the dye with water.


Fig. 25.8 Prepare stock solutions.

4. Preparation of dye stock solution

The colour of a fabric is determined by the ratio of the dyes combined. The quantity of dye according to this ratio is calculated relative to the weight of fibre. For example, to dye 100g of fibre with a 2% depth of shade, 2g of the dye of 100% concentration is required. If the weight of fibre is relatively large, dyeing using a single colour would be simple; measure out powdered dye relative to the weight of fibre. However, to dye a light colour with a small amount of dye, a high-precision chemical balance would be necessary. Therefore, a stock solution containing a uniform dye concentration is prepared, and the required amount of dye is measured from there. The method of preparing a stock solution is the same for all the dyes in Table 25.1.

4.1 Calculation of dye solution[10]

Generally, 250ml of a dye solution of 0.2% (w/v) concentration is prepared. This is equivalent to the concentration obtained by dissolving 0.2g of the dye of 100% concentration in 100 ml of water. The amount of dye is calculated by the following equation.

C = (Concentration of dye stock) (%)
X = (Mass of dye powder) (g)
S = (Strength of dye powder) (%)
V = (Volume of solution) (ml)

$$\text{C Concentration of dye stock (\%)} = \frac{\text{X Mass of dye powder (g)} \times \text{S Strength of dye powder (\%)}}{\text{V Volume of solution (ml)}}$$

To make 250 ml of 0.2 % stock solution with 100 % concentration dye, the calculation is as follows.

$$0.2 = \frac{X \times 100}{250}$$

$$X = \frac{0.2 \times 250}{100} = 0.5\text{ g}$$

A. 0.5 g

To make 250 ml of 0.2 % stock solution with 182 % concentration dye, the calculation is as follows.

$$0.2 = \frac{\dfrac{X \times 100}{182}}{250}$$

$$X = \frac{0.2 \times 250}{182} = 0.27\text{ g}$$

A. 0.27 g

5. Calculation of dye relative to the depth of shade of fibre[11]

The required amount of dye solution relative to the depth of shade of fibre is calculated by the following equation. This is the same for all the dyes in Table 1.

V = Volume of stock solution (ml)
W = Weight of fibre (g)
P = Power of depth of shade of fibre (%)
C = Concentration of stock solution (%)

$$V \quad \text{volume of stock solution} = \frac{W \ \text{weight of fibre} \times P \ \text{depth of shade of fibre}}{C \ \text{concentration of stock solution}}$$

To dye 5 g of fabric with a 3 % depth of shade, the amount of 0.2% stock solution is as follows.

$$V = \frac{5 \times 3}{0.2} = 75$$

A. 75 ml

5.1 Calculation of the amount of dye in dye mixtures

Fabrics used for textile conservation often require precise colour matching. Therefore, dyes are often mixed. The basis is 3 primary colours recommended by the manufacturer. If the colour is close, other dyes may be used as well. However, the maximum number of dyes that can be combined is 4. The amount (V) of each dye is calculated by dividing the proportion (depth of shade) (P) of fibre relative to the weight (W) of fibre, by the dye concentration (C) (for equation, see 5.).

● To dye 5 g (W) of fabric with Yellow 2R and Red 2B to an orange colour in 2 % (P), depth of shade with 0.2 % (C) stock solution, the amount of dye solution (V) for each colour is as follows.

Concentration of stock % (C)	Colour/ ID/ concentration %	Depth of shade of fabric % (P) 2%	
		% (P)	ml (V)
0.2	Yellow 2R 100	0.5	12.5
0.2	Red 2B 100	1.5	37.5

Yellow 2R

$$V = \frac{5 \times 0.5}{0.2} = 12.5$$

A. 12.5 ml

Red 2B

$$V = \frac{5 \times 1.5}{0.2} = 37.5$$

A. 37.5 ml

Fig. 25.9 Cotton, silk wool (JIS standard fabric for sample dyeing)

Fig. 25.10 Weigh the fibre.

Fig. 25.11 Measure and combine the stock solution by calculating the depths of shade, and amount of dye according to the weight of fibre.

Fig. 25.12 Measure the stock solution with a mess cylinder.

Fig. 25.13 For small amounts, measure the stock solution with pipets.

Fig. 25.14 Silk filament thread in a skein and after preparing for dyeing.

Fig. 25.15 Tie two areas of the skein and cut in between.

Fig. 25.16 Plait loosely.

Fig. 25.17 Silk thread after dyeing.

6. Calculation of the total amount of water[12]

Water is necessary to disperse the dye for it to be impregnated into the fibre. The amount of water to put in a dye bath depends on the volume of fibre as well as the shape of the container. As a guideline, the amount of water is approximately 20-100 times the weight of the fibre. The Liquor Ratio, L.R., refers to the ratio of water to the weight of fibre.

Total liquor (T.L.) = ratio × weight of fibre

Liquor Ratio (L.R.) = 1 : 60 fibre 1 g : water 60 ml

The total liquor for L.R. = 1 : 60 and fabric weight 5 g is as follows.

L.R. = 1 : 60
T.L. = 60 × 5 = 300 A. 300 ml

6.1 Amount of water to be added

The Total Liquor includes the dye solution and auxiliary agents. Therefore, the amount of water measured is obtained by subtracting these from the total liquor (T.L.).

Total liquor (T.L.) − (dye solution + liquid levelling agents) =
amount of water to measure (ml)

7. Pre-treatment of cloth and thread

Machine oil, natural oils in wool, dirt and stains adhered to fibres cause uneven dyeing. Fabric and threads should be pre-washed to remove these impurities. Threads are less tangled when loosely plaited before dyeing[13] (Figure 25.14-17).

7.1 Check for fluorescent brightener of cotton fabric and thread

A fluorescent brightener is a kind of anionic dye which absorbs ultraviolet radiation and emits blue fluorescence to enhance the appearance of whiteness. It is used especially for cotton. Since fluorescent brighteners dissolve in water and may leach out, fabric or thread which will be in contact with historic textiles should be selected from those without fluorescent brighteners. Check under a UV lamp.

7.2 Check for starch stains and polyvinyl alcohol (PVOH) adhesives in cotton cloth and thread[14]

Cotton is often starched or coated with polyvinyl alcohol to prevent breaking during weaving. Some fabrics use starched warps with unstarched wefts. A cloth with PVA feels slightly tacky to the touch and can be removed with hot water treatment. However, since starch is not water soluble and interferes with dyeing, fabrics free from starch are selected, or the starch is removed by hot water, scouring or enzymes. The presence of starch can be detected by a spot test using an iodine solution*.

① Place a small piece of fabric or yarn on a dish.
② Wet the sample and apply drops of iodine solution.
③ Observe the colour.

*Preparation reagent: dissolve 2 g potassium iodine in 100ml distilled water and add 1 g iodine and mix well.

7.3. Hot water treatment

Hot water treatment is performed to remove impurities adhered to fibres. Cotton and wool are washed in hot water at 60-70°C for 20-30 minutes. Silk is washed in hot water at around 40°C. Although starch does not dissolve in water, once a certain temperature is reached, it will swell, and with mechanical agitation, it will separate from the fibre. PVA is water-soluble, when heated it softens and swells, and with mechanical agitation, it will be removed. The oil melts with heat.

7.4 Scouring of cotton[15]

When impurities cannot be removed by hot water treatment, scouring is performed with a detergent.

① L.R. : 1:10
① Detergent
  0.1% w/v sodium tripolyphosphate
  0.3% w/v sodium dodecyl sulphate (sodium lauryl sulphate (SDS) e.g. Orvus* VA Paste) 0.05% w/v sodium carboxymethyl cellulose (SCMC)
  (If the above agents cannot be obtained, non-ionic household detergent is adequate. For the amount, follow the instructions by the manufacturer.)
③ Temperature: 90-100℃
④ Time: 30 minutes
⑤ Rinse well.

7.5 Enzymatic removal of starch

Starch may be removed from cotton using enzymes.

① Use enzymes such as diastase or α -amylase around 0.1-0.01% (w/v).
② Total liquor (ml) = × 5 fabric size
③ Temperature: 40℃
④ pH = 4.5-5.5
⑤ Immersion time: 40-120 minutes. Cut off a small piece of fabric during immersion and check with iodine for starch removal.
⑥ Rinse well.
⑦ Use iodine to check the effectiveness of the starch removal.

7.6 Scouring of wool[16]

Impurities, such as natural oil, spinning oil and dirt, adhere to wool. To remove these impurities wool is either subjected to a hot water treatment or washed with a detergent. Since wool is easily damaged by alkali, a neutral detergent is used instead of soap. Wool felts with friction, moisture, and rapid temperature change thus care should be taken when handling.

① L.R. = 1:10

② Detergent

1 ml/1 non-ionic detergent e.g. Dehypon® LS45

0.1 ml/ 1 sodium dodecyl sulphate (SDS) e.g. Orvus® VA Paste

(If the above agents cannot be obtained, non-ionic household detergent is adequate. For the amount, follow the instructions by the manufacturer.)

③ pH = 6.5 -7.5

④ Temperature: 40℃

⑤ Time: 10-20 minutes

⑥ First rinse with warm water and then with cold water.

Fig. 25.18 Hot water treatment of fibre.

Fig. 25.19 While dyeing spread the fabric and constantly move it towards the front and back.

Fig. 25.20 Rinse well after dyeing.

Fig. 25.21 Remove excess water with a towel.

Fig. 25.22 Iron the fabric and align the weave.

8. Dyeing processes

8.1 Preparation of dye solution (stock solution)

250ml of dye solution is prepared at a concentration of 0.2% as a stock solution. After measuring out the dye, work the dye into a paste with a small amount of water, and dissolve the dye with the remainder of the water. Dyes dissolve well in hot water. For colour reproducibility, a chemical balance which can be measured to 0.00g is preferred so that it is possible to measure out the dye precisely. Since stains will occur if the dye powder is scattered, place the scale on a tray, and enclose it all around with thick paper. If the dye is scattered, wipe it off with a dry tissue. Wear a lab coat, gloves, goggles, and a mask.

8.2 Calculation and measurement of dye and auxiliary agents relative to the depth of shade and weight of fibre

For colour reproducibility, it is essential to measure out the dye solution and auxiliary agents accurately. For that purpose, a measuring cylinder and measuring pipettes are used. When dyeing two or more colours simultaneously (as in sample dyeing), put identification labels on the containers, as well as on the pieces of fabric, so that there is no mix-up. Record the dyeing process on a dyeing record sheet.

① Weigh the fabric when dry before washing.
② Calculate and measure stock solution according to 4. When mixing dyes, combine them in one beaker.
③ Calculate and measure water according to 6.
④ Calculate and measure the levelling agent. Calculate and measure additives such as sodium sulphate (Glauber's salt Na_2SO_4). Determine the amount according to the products required.

8.3 Dyeing (Fig. 25.24~25.31)

Pre-soak the fabric and thread in water so that the dye passes easily through them, preventing patchy dyeing. Use a stainless-steel container for a dye bath and heat with an electric heater. When dyeing small fabric samples, place glass beakers in a stainless-steel container with water, and then apply heat.

Dyeing is practised according to the dye cycle given for each dye. The dye bath should be stirred well, using glass or stainless-steel rods. To dye the fabric uniformly, hold the cloth at both ends, and move it forwards and backwards, avoiding pulling it out of the dye solution to prevent crumpling and an influx of air. Rinsing should be carried out until no more colour comes out.

8.4 Drying (Fig. 25.21~25.22)

If a fabric is wrung tightly, wrinkles will become difficult to remove. Therefore, drain off the water lightly, lay the fabric out on a towel, and roll it up to remove the water.

Dry the fabric indoors, and when half-dry, straighten the weave with an iron. The thread is dried with a towel, and when it is half-dry, put both hands into the reel, and pull and straighten it out. The wool yarn has a strong tendency to twist, so it may be dried using suspended weights to help straighten the fibres. Fabric and thread intended for use in conservation treatments should be acclimatized to the room environment at least for a week before use.

9.Dyeing cellulose fibres (cotton, linen)

9.1 Dyeing method for Solophenyl® dye[17-18]

Solophenyl® dyes graded above blue wool standard 5 are listed in Table 25.3. The amount of sodium sulphate is listed in Table 25.4. The Tricolour combination recommended by the manufacturer is as below.

Yellow: Yellow ARLE or Orange ARLE
Red: Bordeaux 3BLE
Blue: Blue TLE
Levelling agent: 0.5 g/l Albegal® A or Albatex® AR or
Albatex® LD (anionic) of the total liquor
Retarding agent: Add sodium sulphate according to total liquor (Table 25.4).)

Table 25.3 Fastness of Solophenyl® dyes (cotton)

Solophenyl®		Light fastness (Xenon Lamp) Blue wool standard grade	Wash fastness grade (40℃)
Yellow ARLE	154 %	5	4
Orange ARLE	220 %	5-6	4-5
Orange TGL	182 %	5-6	4-5
Bordeaux 3BLE	100 %	5	4-5
Blue TLE	100 %	5	4
Turquoise BRLE	400 %	5-6	2-3
Navy BLE	250 %	5	3

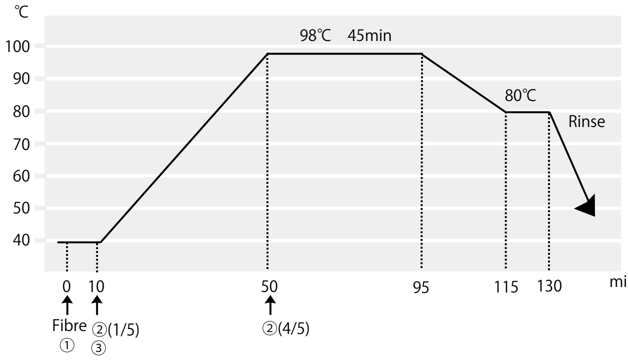
Table 25.4 Retarding agent (sodium sulphate Na_2SO_4, Glauber's salt)

Depth of shade（P）%	Amount (g/l)	
	Colour of dye: general	Special colour: Turquoise BRLE
0.05 – 0.1	1-2	5 – 7.5
0.1-0.25	2-5	7.5-10
0.25-0.5	5 – 7.5	10-15
0.5-0.75	7.5 – 10	15-20
0.75-1	10-15	20-30
1 – 1.25	15 – 17.5	30-35
1.25 – 1.5	17.5 – 20	35-40
1.5 – 2.5	20 – 25	40
➢ 2.5	25	40

Fig. 25.23 Retarding agent: Sodium sulphate (Na_2SO_4)

9.1.1 Solophenyl® dye cycle

Wet out the fibre. Put the fibre and dye in the bath at 40℃. After 10 minutes, take out the fibre, add 1/5 of the sodium sulphate and levelling agent into the bath and return the fibre. Gradually raise the temperature to boiling point over 40 minutes. Add the rest of the sodium sulphate into the bath. Turquoise BRLE requires 1/4 of sodium sulphate after 10 minutes and 3/4 after boiling. Maintain the temperature for 45 minutes. Gradually lower the temperature to 80 ℃ over 20 minutes and maintain the temperature for 10 minutes. Rinse with warm water, followed by cold water, gradually lowering the temperature. Rinse well until no more colour washes out of the fibre.



① Solophenyl® dye

② Retarding agent: sodium sulphate Na_2SO_4 (Table 25.4)

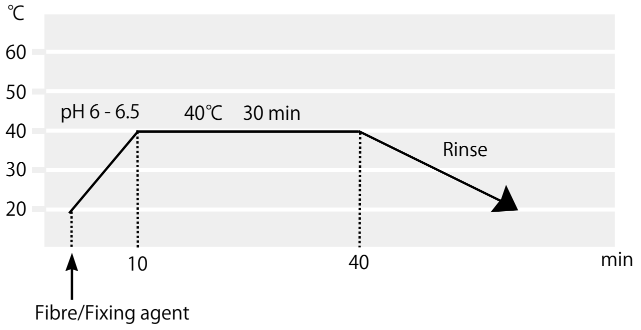
③ Levelling agent: 0.5 g/l Albegal® A or Albatex® AR or
0.5g/l Albatex® LD (anionic) of the T.L.

9.1.2 Fixing agent

Dark colours (above 2%, below 5%) require a fixing treatment. Add the fixing agent to the total liquor and adjust the pH to 6-6.5 (using acetic acid or ammonia). After dyeing, insert the fibre into the fixing solution at 20℃, raise to 40℃ within 10 minutes, maintain for 30 minutes, and then rinse well.

Table 25.5 Fixing agent

Dye	Fixing agent	Ammount (g)
Solophenyl®	Albafix® FRD Albafix® ECO	1-3 % o.w.f. 1-3 % o.w.f.



9.2 Dyeing method for Sirius® Dye [19-20]

Sirius® dyes graded above blue wool standard 5 are listed in Table 25. 6. The amount of sodium sulphate is listed in Table 25.7. The tricolour combination recommended by the manufacturer is as below.

Yellow: Yellow K-CF or Orange ARLE
Red: Scarlet KCF (blue scale grade is 4)
Blue: Blue K-BE
Levelling agent: 0.2-1 g/l Levagal ED of the total liquor
Retarding agent: Add sodium sulphate according to the total liquor of the depth of shade of fibre (dyeing colour).

Table 25.6 Fastness of Sirius® dyes (cotton)

Sirius®		Lightfastness (Xenon Lamp) Blue wool standard grade	Wash fastness grade（40℃）	Best dyeing temperature （℃）
Yellow S-2G	100 %	5	2-3	70-90
Yellow R	100 %	5-6	2-3	50-70
Yellow KCF	100 %	5-6	3-4	70-80
Orange 3GDL	100 %	6	2-3	60-80
Orange K-CFN	100 %	5-6	3-4	70-80
Scarlet BN	100 %	5	5	80
Scarlet K-CF	100 %	4	2	90
Red F4BL	100 %	5	3	95
Red Violet RL	100 %	5	2-3	80-95
Blue K-CFN	100 %	5	2	70-80
Blue F5GL	100 %	6	3	80
Blue K-BE	100 %	5-6	-	-
Turquoise GL	100 %	5-6	3	80-95
Turquoise S-FBL	100 %	6	3-4	95
Brown 3RL	100 %	5	2-3	95
Navy BLE	250 %	5	3	80-90

Table 25.7 Retarding agent (sodium sulphate Na_2SO_4, Glauber's salt)

Depth of shade（P）%	Amount（g/l）	
	Dye colour: general	Dye colour: Turquoise GL Turquoise S-FBL
< 0.25	1.5	2.5
0.25-0.5	2.5	5
0.5-1	5	10
1.0-2.0	7.5	15
2.0 <	12.5	25


Fig. 25.24 Soak the fibre.


Fig. 25.25 Remove the fibre, add the dye, mix well and reinsert the fiber.


Fig. 25.26 Remove the fibre, add the auxiliary agents, mix well, and reinsert the fibre.


Fig. 25.27 Cool down and rinse well.


Fig. 25.28 Rinse well.

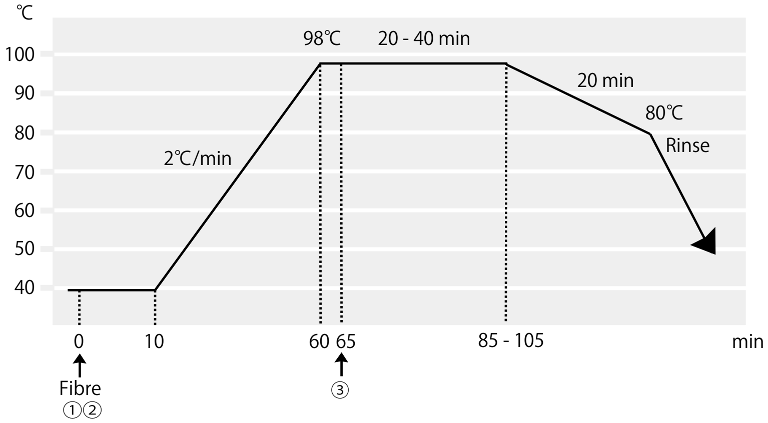

Fig. 25.29 Towel dry the samples.


Fig. 25.30 Iron the samples.


Fig. 25.31 Colour triangle (cotton)

9.2.1 Sirius® dye cycle [19-20]

Wet out the fibre. Put the fibre, dye and levelling agent in the bath at 40℃. After 10 minutes, gradually raise the temperature to boiling point in 50 minutes. After 5 minutes of boiling, add sodium sulphate. Maintain the temperature for 20-40 minutes. Gradually lower the temperature to 80 ℃ within 20 minutes. Rinse with warm water and then with cold water, gradually lowering the temperature. Rinse well until no colour runs out of the fibre.



① Sirius® dye

② Levelling agent: 0.2-1 g/l Levagal ED of the total liquor

③ Retarding agent: sodium sulphate (Na_2SO_4) (Table 25.7)

9.2.2 Fixing agent

The amount and procedure are as follows.

Table 25.8 Fixing agent

Dye	Fixing Agent	Amount (g)
Sirius®	Levogen®	1-3 % o.w.f.
	Tinofix® N	1-3 % o.w.f.
	Tanafix N (Japanese maker)	2-5 ml/l
	Fix A (Japanese maker)	10-20 ml/l

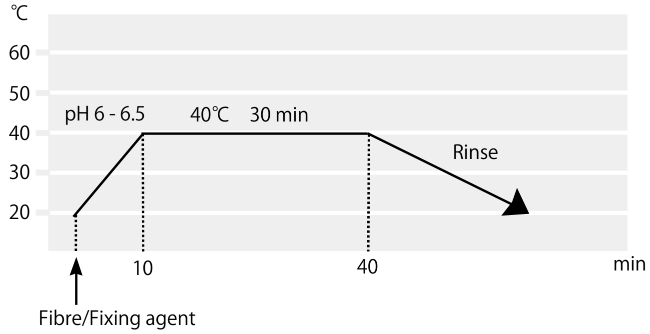


Fig. 25.32 Levelling agent (Lanaset salt 20)

Fig. 25.33 Primary colours. red, blue and yellow stock solution.

Fig. 25.34 Soak the fibre.

Fig. 25.35 Remove the fibre, add the reagents, mix and then re-insert the fibre.

Fig. 25.36 Lift up the fibre and add the additives.

10. Dyeing of protein-based and amide-based fibres (silk, wool, nylon) Lanaset® and Irgalan® dye cycle

The isoelectric point of wool is pH 4.5, and that of silk is pH 5.1[21]. This is the pH at which the fibre is most chemically stable. An acid dye is used which fixes with the fibre under acidic conditions. As for temperature, wool can bare high temperatures (98 °C), but silk hardens and loses its pliability, so it is dyed at around 80°C.

10.1 Levelling agent

Albegal® SET and Albegal® FFA contain surfactants and amphoteric compounds and react with both acids and bases. These reagents disperse the dye in the dye bath, assist its transfer into the fibres, and have the function of fixing the dye uniformly. 1% o.w.f. is generally used. However, for a bath ratio of less than 1:8 8:1, 0.5% is used, while for a bath ratio greater than 1:25 25:1, the amount is increased. When dyeing wool yarn with Lanaset, 5-10% o.w.f. sodium sulphate is added[22].

10.2 pH regulating agents and retarding agents for dye baths

Irgalan® and Lanaset® dyes are optimally used at a pH 4.5 for wool and pH5 with silk which matches the isoelectric point of wool or silk. To adjust the pH, use sodium acetate or acetic acid, or use a buffer which maintains a constant pH of 4.5 such as Albatex® AB-45 (anion type, no acid required). If a buffer is used, colour reproducibility is easier.

To achieve even dyeing, when dyeing low depth of shade (pale) colours, raise the amount of sodium sulphate, and when dyeing high depth of shade (dark) colours, lower the mount.

10.3 Dyeing method for Lanaset® dyes [23-24]

Lanaset® dye is a mixture of 1:2 metal complex acid dye and reactive dye at the ratio of 1:2. Colours that are graded above blue wool standard 5 are listed in Table 25.9. The tricolour combination recommended by the manufacturer is as below. Adjust the dye bath to pH 4.5-5. The primary colours are as follows.

Yellow: Yellow 2R or Orange ARLE
Red: Red G
Blue: Grey G or Brown B
Levelling agent: 1 % o.w.f. Albegal® SET or 20% o.w.f. Lanaset salt 20
pH adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or
Albatex® AB-45 (30-60 % acetic acid and 3-7% ammonia acetate for adjusting to pH 4.5)
Retarding agent: 5-10 % o.w.f. Sodium sulphate (Glauber's salt Na_2SO_4)

Table 25.9 Fastness of Lanaset® dyes (wool)

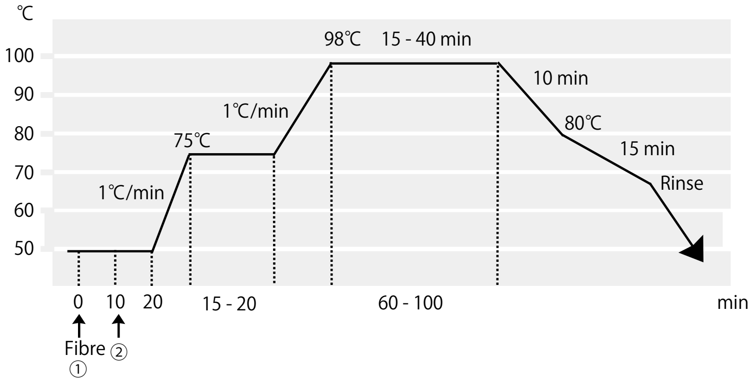
Lanaset®	Light fastness (Xenon Lamp) Blue wool standard grade	Wash fastness grade (40℃)
Yellow 4GN	6	4-5
Yellow 2R	5-6	4
Orange RN	6	4-5
Brown B	6-7	5
Red G	5-6	4-5
Red 2B	5-6	4-5
Bordeaux B	5	4
Violet B	5	4
Blue 2R	5-6	4-5
Blue 5G	5-6	4
Green B	6	4
Gray G	6	4-5
Navy R	5-6	4-5
Black B	6-7	4-5


Fig. 25.37 Colour triangle (wool)

10.3.1 Lanaset® dye cycle for wool

Wet out the fibre. Add the levelling agent, pH adjusting agent and retarding agent into the bath at 50℃, adjust the pH to 4.5 and re-insert the fibre. After 10 minutes, remove the fibre, pour in the dye, mix well and re-enter the fibre. After 10 minutes gradually raise the temperature to 75 ℃ and maintain for 15 to 20 minutes. Raise to 98 ℃ and maintain the temperature for 15-40 minutes. Gradually lower the temperature to 80 ℃ in 10 minutes and lower further for 15 minutes. Rinse with warm water and then with cold water, gradually lowering the temperature. Rinse well until no colour runs out of the fibre.

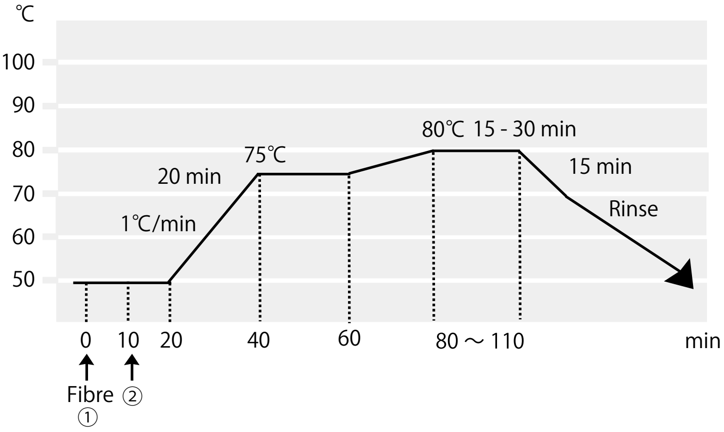

Fig. 26.38 Colour triangle (silk)



① Levelling agent and pH adjusting agent and retarding agent
Levelling agent: 1 % o.w.f. Albegal® SET or Albegal® FFA or
20% o.w.f. Lanaset salt 20 pH
Adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or Albatex® AB-45
(buffer pH 4.5)
Retarding agent: 5-10 % o.w.f. Sodium sulphate (Na_2SO_4)
② Lanaset® dye

10.3.2 Lanaset® dye cycle for silk

Wet out the fibre. Insert the fibre in the bath at 50 ℃ with levelling agent, pH adjusting agent and retarding agent. Adjust the pH to 5. After 10 minutes, remove the fibre again, add the dye, re-insert the fibre and mix well. After 10 minutes, gradually raise the temperature to 75℃ within 20 minutes. Maintain for 20 minutes and raise the temperature to 80 ℃ within the next 20 minutes and maintain the temperature for 15-30 minutes. Gradually lower the temperature for 15 minutes. Rinse with warm water and then with cold water, gradually lowering the temperature. Rinse well until no colour runs out of the fibre.



① Levelling agent and pH adjusting agent and retarding agent

Levelling agent: 1 % o.w.f. Albegal® SET or Albegal® FFA or
20% o.w.f. Lanaset salt 20 pH

Adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or
Albatex® AB-45 (buffer pH 4.5)

Retarding agent: 5-10 % o.w.f. Sodium sulphate (Na_2SO_4)

② Lanaset® dye

10.4 Irgalan® dye cycle for protein fibres[25]

Irgalan® is a 1:2 metal complex acid dye. It has a dull colour range compared with Lanaset®. Colours that are graded above blue wool standard 5 are listed in Table 25.10. The procedure for dyeing is the same as Lanaset®. The tricolour combination recommended by the manufacturer is as below.

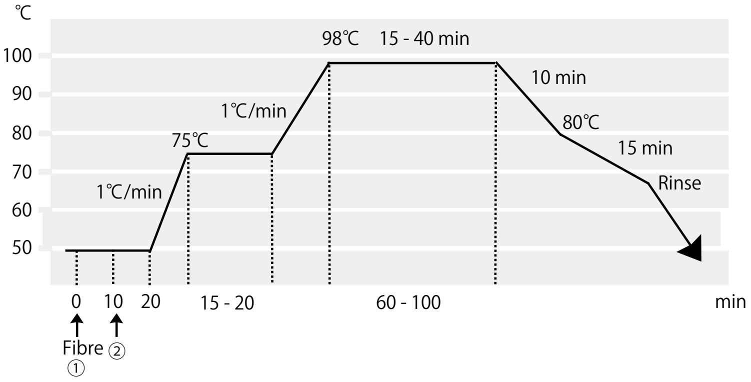
Yellow: Yellow 3RL
Red: Bordeaux EL
Blue: Grey GLN
Black: Black BGL, Black RBLN
Levelling agent: 1 % o.w.f. Albegal® SET or Albegal® FFA or
20% o.w.f. Lanaset salt 20
pH adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or
Albatex® AB-45 (buffer, pH 4.5)
Retarding agent: 5-10 % o.w.f. Sodium sulphate (Na_2SO_4)

Table 25.10 Fastness of Irgalan® dyes (wool)

Irgalan®		Light fastness (Xenon Lamp) Blue wool standard grade	Wash fastness grade (40℃)
Yellow 2GL	250%	5	5
Yellow GRL	200%	6-7	4-5
Yellow 3RL	250%	6-7	4-5
Orange RL	250%	6	5
Red 2GL	200%	5-6	4-5
Bordeaux EL	200%	6	4
Blue 3GL	200%	5-6	4-5
Gray GLN	100%	6-7	4-5
Gray BL	200%	5	4-5
Black BGL	200%	7	5
Black RBLN	100%	7-8	5

10.4.1 Irgalan® dye cycle for wool

Wet out the fibre. Insert the fibre in the bath at 50 ℃ . After 10 minutes, remove the fibre, pour in the levelling agent and adjust the pH to 5.0. Mix well and re-enter the fibre. After 10 minutes, remove the fibre again, add the dye and re-insert the fibre. Gradually raise the temperature to 70 ℃ within 20 minutes and maintain the temperature for 20-60 minutes. Gradually lower the temperature for 15 minutes. Rinse with warm water and then with cold water, gradually lowering the temperature. Rinse well until no colour runs out of the fibre. Adjust the dye bath to pH 5.0.



① Levelling agent and pH adjusting agent

Levelling agent: 1 % o.w.f. Albegal$^{®}$ SET or Albegal$^{®}$ FFA or
20% o.w.f. Lanaset salt 20 pH

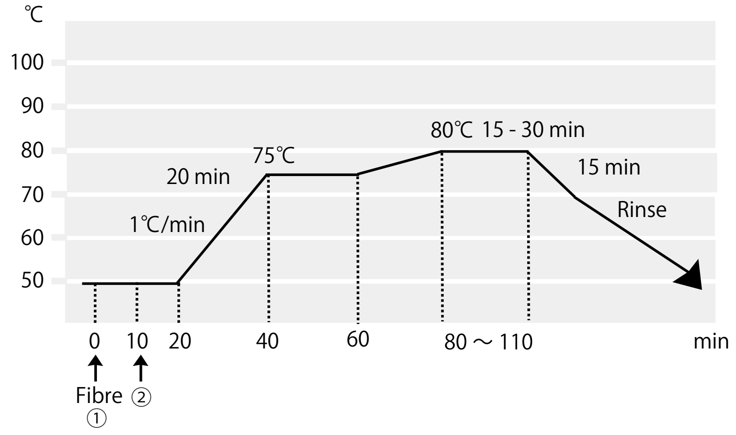
Adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or Albatex$^{®}$ AB-45
(buffer pH 4.5)

Retarding agent: 5-10 % o.w.f. Sodium sulphate (Na_2SO_4)

② Irgalan$^{®}$ dye

10.4.2 Irgalan$^{®}$ dye cycle for silk

Wet out the fibre. Insert the fibre in the bath at 50℃. After 10 minutes, remove the fibre, pour in the levelling agent and adjust the pH to 5.0. Mix well and re-enter the fibre. After 10 minutes, remove the fibre again, add the dye and re-insert the fibre. Gradually raise the temperature to 70 ℃ within 20 minutes and maintain the temperature for 20-60 minutes. Gradually lower the temperature for 15 minutes. Rinse with warm water and then with cold water, gradually lowering the temperature. Rinse well until no colour runs out of the fibre. Adjust the dye bath to pH 5.0.



① Levelling agent and pH adjusting agent

Levelling agent: 1 % o.w.f. Albegal$^{®}$ SET or Albegal$^{®}$ FFA or
20% o.w.f. Lanaset salt 20 pH

Adjusting agent: 1 g/l sodium acetate or 80 % acetic acid or
Albatex$^{®}$ AB-45 (buffer pH 4.5)

Retarding agent: 5-10 % o.w.f. Sodium sulphate (Na_2SO_4)

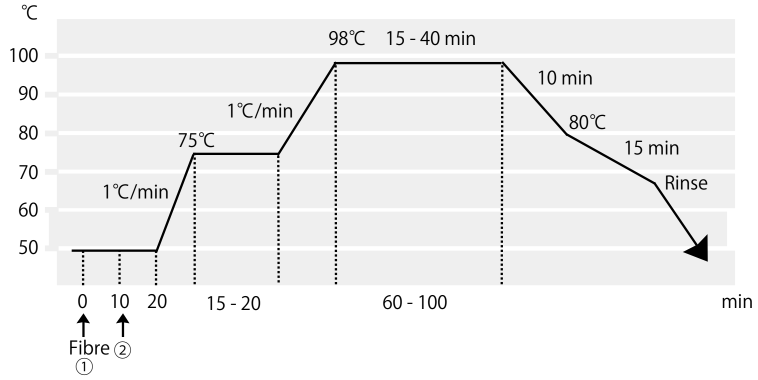
② Irgalan$^{®}$ dye

10.5 Dyeing with reactive dyes: Levafix® and Remazol® dye cycle[26]

Reactive dyes such as Levafix® and Remazol® are suitable for dyeing cellulose fibres. When dyeing paper, attach the paper to a rod with pegs or clips during dyeing or sandwich the paper between two sheets of non-woven polyester.

10.5.1 Levafix® Dyeing

Wet out the fibre. Add sodium sulphate (Na_2SO_4 Glauber's salt) into the bath at 25-30℃, and then insert the fibre. Maintain this temperature for 10 minutes before adding the dye. After 30 minutes add in the sodium carbonate (Na_2CO_3 soda ash). Following 20 minutes of fixation, gradually raise the temperature to 60℃. The duration time at 60℃ depends on the depth of shade of the fibre.



① Fiber and sodium sulphate

② Dye

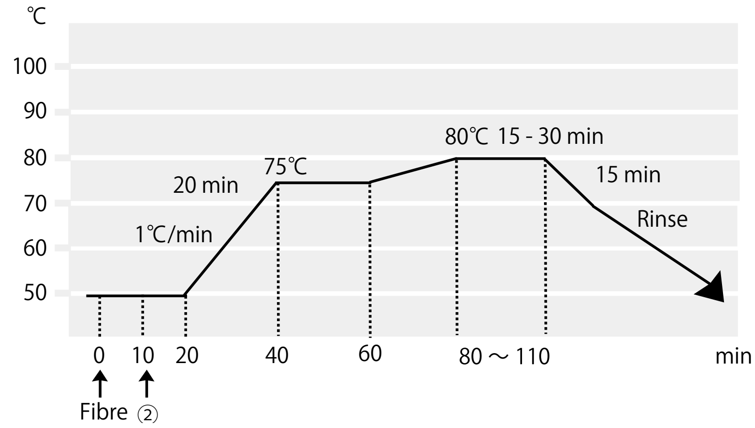
③ Sodium carbonate

Table 25.11 Additive and fixation time for Levafix®

	Depth of shade (%)						
	<0.1	**0.1-0.5**	**0.5-1.0**	**1.0-2.0**	**2.0-3.0**	**3.0-5.0**	**>5.0**
Sodium sulphate g/l	15	15-20	20-35	35-50	50-60	60-80	80
Sodium carbonate g/l	5	5-7	7-10	10-13	13-15	15-20	20
Fixation time	30	30	45	45	60	60	60

10.5.2 Remazol® Dyeing

Wet out the fibre. Add sodium sulphate into the bath at 25-30℃, and then insert the fibre. Maintain this temperature for 10 minutes before adding the dye. After 30 minutes add the first alkali addition, maintaining the temperature for 20 minutes. Gradually raise the temperature to 60℃ and after 10 minutes at the temperature add the second alkali addition. Fix for 20-40 minutes depending on the depth of shade of fibre.



①Fibre and sodium sulphate
②Dye
③Sodium carbonate 3/1 or 1/2
④Sodium carbonate 2/3 or 1/2

Table 25.12 Additive and fixation time for Remazol®.

Additive	Depth of shade (%)						
	<0.1	0.1-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-5.0	>5.0
Sodium sulphate g/l	20	20-25	25-40	40-50	50-60	60-80	80-100
Sodium carbonate g/l	5	5-7	7-10	10-13	13-15	15-20	20
① Alkali addition	1/3 sodium carbonate				1/2 sodium carbonate		
② Alkali addition	2/3 sodium carbonate				1/2 sodium carbonate		
Fixation time	15	15	15	30	30	30	30

Practice: Primary colours and mixed colours

Produce a colour triangle with primary colours and mixed colours.

Photocopy this sheet and attach the dyed fabric.

Fibre:

Red dye
Blue dye:
Yellow dye:

Depth of shade of fibre: 2%

Red
① Red 2%

Red＋Blue
④ Red 1% : Blue1%

Red＋Blue＋Yellow
⑦ R0.66 : B0.66 : Y0.66%

Red＋Yellow
⑤ Red 1% : Yellow 1%

Blue
②Blue 2%

Blue＋Yellow
⑥ Blue 1% ： Yellow 1%

Yellow
③ Yellow 2%

Cellulose fibre Solophenyl®		1		2		3		4		5		6		7		8		Date
① Weight of fibre (W)		g		g		g		g		g		g		g		g		Name
Percentage of the depth of shade %(P)		%		%		%		%		%		%		%		%		Object ID
Concentration of Stock % (C)	② Dye colour / ID/ %	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	0.2% (w/v) 250ml
	②																	Note
	②																	
	②																	
	②																	
③ Liquor Ratio (L.R.) (Fiber：Water)		:		:		:		:		:		:		:		:		
④ Total Liquor (T.L.) (Weight of fiber× L.R.)		ml		ml		ml		ml		ml		ml		ml		ml		
⑤ Levelling agent		ml		ml		ml		ml		ml		ml		ml		ml		
⑥ Retarding agent Sodium sulphate(Na_2SO_4)		g		g		g		g		g		g		g		g		
⑦ Dye stock and leveling agent ② ＋ ⑤		ml		ml		ml		ml		ml		ml		ml		ml		
⑧ Amount of water ④ − ⑦		ml		ml		ml		ml		ml		ml		ml		ml		
⑨ Fixing agent（dark colours) P=2%< 1-3% o.w.f		ml		ml		ml		ml		ml		ml		ml		ml		
Information of fibre・Undyed fibre		Sample		Sample		Sample		Sample		Sample		Sample		Sample		Sample		

Cellulose fibre Sirius®		1		2		3		4		5		6		7		8		Date
① Weight of fibre (W)			g		g		g		g		g		g		g		g	Name
Percentage of the depth of shade %(P)			%		%		%		%		%		%		%		%	Object ID
Concentration of Stock % (C)	② Dye colour / ID	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	0.2% (w/v) 250ml
	②																	Note
	②																	
	②																	
	②																	
③ Liquor Ratio (L.R.) (Fibre：Water)		:		:		:		:		:		:		:		:		
④ Total Liquor (T.L.) (Weight of fibre×L.R.)			ml		ml		ml		ml		ml		ml		ml		ml	
⑤ Levelling agent			ml		ml		ml		ml		ml		ml		ml		ml	
⑥ Retarding agent Sodium sulphate (Na_2SO_4)			g		g		g		g		g		g		g		g	
⑦ Total of dye stock and levelling agent ② ＋ ⑤			ml		ml		ml		ml		ml		ml		ml		ml	
⑧ Amount of water ④ － ⑦			ml		ml		ml		ml		ml		ml		ml		ml	
⑨ Fixing agent (dark colours) P=2%<1-3% o.w.f			ml		ml		ml		ml		ml		ml		ml		ml	
Information of fibre・Undyed fibre		Sample		Sample		Sample		Sample		Sample		Sample		Sample		Sample		

Protein, polyamid fibre (wool, silk, nylon) Lanaset® • Irgalan®		1		2		3		4		5		6		7		8		Date
① Weight of fibre (W)		g		g		g		g		g		g		g		g		Name
Percentage of the depth of shade %(P)		%		%		%		%		%		%		%		%		Object ID
Concentration of Stock %(C)	② Dye colour / ID	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	0.2% (w/v) 250ml
	②																	Note
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③ Liquor Ratio (L.R.) (Fibre : Water)		:		:		:		:		:		:		:		:		
④ Total Liquor (T.L.) (Weight of fibre× L.R.)		ml		ml		ml		ml		ml		ml		ml		ml		
⑤ Levelling agent		ml		ml		ml		ml		ml		ml		ml		ml		
⑥ pH adjusting agent (pH 4.5-5)																		
⑦ Retarding agent (5~10% o.w.f) Sodium sulphate (Na_2SO_4)		g		g		g		g		g		g		g		g		
⑧ Total of dye stock and levelling agent ② + ⑤		ml		ml		ml		ml		ml		ml		ml		ml		
⑨ Amount of water ④ − ⑧		ml		ml		ml		ml		ml		ml		ml		ml		
Information of fibre • Undyed fibre		Sample		Sample		Sample		Sample		Sample		Sample		Sample		Sample		

Cellulose Fibre Reactive dye：Levafix® ・Remazol®		1		2		3		4		5		6		7		8		Date
① Weight of fibre (W)		g		g		g		g		g		g		g		g		Name
Percentage of the depth of shade %(P)		%		%		%		%		%		%		%		%		Object ID
Concentration of Stock % (C)	② Dye colour / ID	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	%(P)	ml (V)	
	②																	Note
	②																	
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③ Liquor Ratio (L.R.) (Fibre：Water)		:		:		:		:		:		:		:		:		
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⑤ Sodium sulphate (Na_2SO_4)		g		g		g		g		g		g		g		g		
⑥ Sodium carbonate （Na_2CO_3）		g		g		g		g		g		g		g		g		
⑦ Amount of water=④		ml		ml		ml		ml		ml		ml		ml		ml		
Information of fibre・Undyed fibre		Sample		Sample		Sample		Sample		Sample		Sample		Sample		Sample		

Manufacturer and distributor

Solophenyl® (cellulosics) Albatex® LD (levelling agent) Albafix® FRD (fixing agent) Albafix® ECO (fixing agent) **Lanaset**® (protein polyamide) Albegal® SET (levelling agent) Albatex® AB-55 (acid buffer)	Manufacturer	Huntsman International LLC Textile Effects 4050 Premier Drive High Point, NC 27265 USA Tel.: + 1 800-822-1736 Fax.:+ 1 336-801-2808 Infotexamericas@huntsman.com http://www.huntsman.com/corporate/a/Home
Sirius®(cellulosics) **Levafix®** (cellulosics) **Remazol®** (cellulosics)	Manufacturer	DyStar Textilfarben GmbH & Co. Marketing Dyes for Cellulosics 1 D-65926 Frankfurt am Main, Germany Tel: + 49 (0) 69-2109-25 05 Fax: +49 (0) 69-2109-20- 4 http://www.Dystar.com
Solophenyl® (cellulosics) Albatex® LD (levelling agent) Albafix® FRD (fixing agent) Albafix® ECO (fixing agent) **Lanaset**® (protein polyamide) Albegal® SET (levelling agent) Albatex® AB-55 (acid buffer)	Distributor	Town End (Leeds) Plc Silver Court, Intercity way, Stanningley, Leeds, West Yorkshire, lS13 4LY UK. Tel.: + 44 (0)113 256 4251 Fax.: +44 (0)113 239-3315 http://www.textile-dyes.co.uk/

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Textile Conservation

Chapter 5

Essay

The Wabi-sabi of Boro Rags and the Art of Textile Conservation

Keywords

textile conservation, stitching, wabi-sabi, boro, cultural relativism

Abstract

Wabi-sabi is a Japanese aesthetic described as one of beauty that is "imperfect, impermanent, and incomplete." Boro is a Japanese term mean- ing rags. This paper compares the Japanese at- titudes and aesthetics regarding rags and the art of stitching to the mainstream textile con- servation stitching approach developed in the West. The aim is a consideration of the cultural relativism of our profession in order to rethink the "rightness" of our decision-making. Domes- tic cloth-mending techniques, such as darning and patching, are compared with the conscious selection of the textile conservation stitching methods that originated in the West during the past century. Using conservation stitching as living heritage in Japan as an example, this pa- per points out that the selectivity that emerged during the last 100 years, during the develop- ment of a profession in the heritage sector, and the departure from domesticity have narrowed the choices and decision-making possibilities of textile conservators, which can also be reflected in other areas of conservation. The concept of diversity in conservation approaches will not be integrated if a culture is viewed as absolute. A spirit of tolerance and a sense of historical consciousness are necessary to acknowledge differences as an independent culture. The au- thor hopes that the arguments and case studies in this paper will stir an open debate about how to preserve textiles, and spread an awareness that impermanence also has a place in the art of textile conservation.

*The original paper presented at ICOM-CC Beijing in 2021 cited below has been revised with additional photographs for this textbook. I have added this paper in the last chapter to explain the diversity of approaches in textile conservation. The goal of textile conservation is to make textiles last.

Ishii, M. 2021. The wabi-sabi of boro rags and the art of textile conservation. In *Transcending Boundaries: Integrated Approaches to Conservation. ICOM-CC 19th Triennial Conference Preprints, Beijing, 17–21 May 2021*, ed. J. Bridgland. Paris: International Council of Museums.

https://www.icom-cc-publications-online.org/4341/The-wabi-sabi-of-boro-rags-and-the-art-of-textile-conservation

Introduction

> Wabi-sabi is a beauty of things imperfect, impermanent, and incomplete. (Koren 1994)

This paper examines the Japanese attitudes and aesthetics related to stitching and kimono conservation and compares them to Western thinking in textile conservation stitching. Its aim is to understand the cultural relativism of textile conservation and encourage a rethinking of the "rightness" of current decision-making in this field. While studying and working in the UK and the US before returning to her native country, the author did not question the "rightness" of her choices and practices because they followed those of the two countries, which were largely similar. However, upon moving back to Japan, she became aware that the country's conservation culture was noticeably different. Furthermore, the experience gained in teaching textile conservation in countries such as Egypt, Armenia, and Taiwan led her to believe that rightness is relative. Unlike oil painting, textiles are a universal material and their ethnological repair, based on local sewing techniques, has enabled them to be passed on. But how much do we know about practices of mending cloth around the world? Implementing Western methodology imposes an ethnological continuity that precludes a consideration of different perspectives in conservation (Simila and Eastop 2017). An example of ancient darning can be seen in an ancient Egyptian tunic (E.T.60, 178) in the collection of the Fitzwilliam Museum, Cambridge. Technically, there is no difference compared to today's darning, whether Egyptian, British, or Japanese, because the fabric structure of the plain weave cloth is common, and the problem of its damage has been tackled in a similar manner. One could even say that darning is a human tradition. However, when a damaged cloth is handed over to a textile conservator who is systematically trained in the "Western system" (i.e., conservation courses or museum training), a different approach may be adopted, and darning would not be considered as an option. We must examine the reasons for this. The Egyptian tunic has lasted for centuries, with the darning in place and entombed. Surely, darning should be valid in today's museums. The hypothesis is that the selective academic and scientific approach towards stitching in textiles that was adopted in the last century has narrowed our views and restricted choices in preserving historical textiles.

The virtue of stitching

Boro (襤 褸) is a Japanese term for rags, or cloth that is used until it is rendered useless. In the 21st century, as the perfection of things has become less of a commodity, the pleasure inherent in imperfection is becoming increasingly recognized. This global trend can be seen in the popularity of tattered jeans, although they are most often artificially crafted. Coinciding with this shift in values, boro has entered the limelight.

The humble act of piecing fabric and sewing it together or darning layers of fabric to strengthen a piece of cloth seems to have touched the senses of a global culture caught up in materialism. In a 2019 exhibition titled Repair and Design Futures at the Rhode Island School of Design's Art Museum, curator Kate Irvin explained that "Repair invites renewed forms of social exchange and offers alternative, holistic ways of facing environmental, and social breakdown"1 and, quoting Spelman, noting that: "Repair is a creative distraction of brokenness" (Spelman 2003). Yet, the act of piecing tattered fabrics and the aesthetic appreciation behind boro can be better traced to Buddhism, in which mending is seen as an act of virtue.

Funzōe (糞掃衣), literally meaning a cloth to wipe faeces, is a synonym for kesa (袈 裟), which originates from the Sanskrit word kāsāya, a Buddhist monk's robe made from rags. The ragged monk's robe comes from the Buddha, whose sole possession was a rag which not only covered his body but which he also used to sweep the street. A well-known example of a funzōe in Japan dates from the 8th century and belonged to Emperor Shōmu (701–756); it is now preserved at the Shōsōin Treasure House, Imperial Household Agency at Nara. Quilted priest's robe in nine strips of mottled colours, No. 1 (Figure 1) is made of polychrome plain-weave silk


Fig. 26.1 Quilted priest's robe in nine strips of mottled colours, No. 1, a kesa that belonged to Emperor Shōmu (701–756). Courtesy of the Shōsōin Treasure House, Imperial Household Agency.


Fig. 26.2 Emperor Hirohito (left, 1901-1989) and his elementary school uniform (centre). The torn trousers are patched (right). Photo: Courtesy Showa Memorial Museum.

patches stitched together with bast fibre thread using plain stitching. Another example of "virtuous patching" can be seen in the trousers worn by Emperor Hirohito (1901–1989) as a schoolboy, now in the Showa Memorial Museum, Tokyo. The trousers have patches on the knees. While it would have been considered shameful for him to wear clothes with holes, it was not shameful if they had been mended with patches.

In the 16th century, the Buddhist mindset of impermanence was furthered by the aesthetic sense of Sen no Rikyū (千利休, 1522–1591), who had a profound influence on developing the tea ceremony known as wabi-cha, literary meaning forlorn (pitifully sad and abandoned) tea. In the age of Japan's civil wars, Rikyū served as a tea master to the highest-ranking warlords and highly appreciated broken and repaired tea bowls for their added value of imperfection. The impermanence and continuous flux of the universe, mujyo (無常) in Japanese, was expressed by the aesthetics underlying Rikyū's choice of utensils when serving tea. An explanation of wabi-sabi in English is offered by the following, a citation from Koren's provisional definition.

> Originally, the Japanese words "wabi" and "sabi" had very different meanings. "Sabi" originally meant "chilled," "lean," or "withered." "Wabi" originally meant the mystery of living alone in nature, away from society, and suggested a discouraged, dispirited, cheerless emotional state. Around the 14th century, the meanings of both words began to evolve in the direction of a more positive aesthetic value . . . wabi and sabi have crossed over so much that today the line separating them is very blurred indeed. (Koren 1994)

Taking care of a cloth's life until the last thread was an act of virtue in Buddhism. Repair was an aesthetic pleasure, a reminder of the impermanence of the world. Many Japanese historical kimonos seen in museums today were originally cut up, pieced together, and reformed into kesa or an uchishiki (altar frontals) as commemorative offerings to the temple. They were only put together in kimono form when, in the early 20th century, the art market drove their collection and display, and museums started to collect Japanese art.

Repairing and darning

In recent years, the eco-movement and the interest in sustainability have found expression in darning as a hobby or life skill. Sashiko, a reinforcement stitching pattern used to put together patches of boro, has become popular as a functional form of embroidery in countries other than Japan. Similarly, Japanese handicraft enthusiasts are fascinated with Western darning using a wooden "darning mushroom." Colourfully darned clothes have been presented in a recent publication, and kits can be bought that contain a wooden darning mushroom and threads (Noguchi 2018). The author joined a local workshop to learn Western darning from simple curiosity, wondering how Father McKenzie in the Beatles song Eleanor Rigby darned his sock, and a question arose: Why was I not taught this during my conservation training in the UK or US? How do our approaches as textile conservators differ from this darning method to sustain a sock? Are we sure that our methodology, so "conscious of ethics" and so highly selective in its choice of materials, will ensure the longevity of a sock better than simply darning it? Why do we not darn the socks collected in a museum?

The differences between approaches to domestic vs. historical fabric care derive from an urgent and conscious desire of the pioneers of the 20th-century heritage sector (museums and educational institutions) in Europe and North America to depart from domesticity and become part of an academic establishment. Thus, the humble act of stitching was consciously and systematically transformed, resulting in techne, an implication of knowledge or principle and synonymous with art. The result was the field of textile conservation, which incorporates Western philosophy, science, and technique into needlework in an approach that cannot be achieved by domestic education alone. Yet, among the various methodologies within textile conservation today, stitching is a sensitive area. Many textile conservators enter

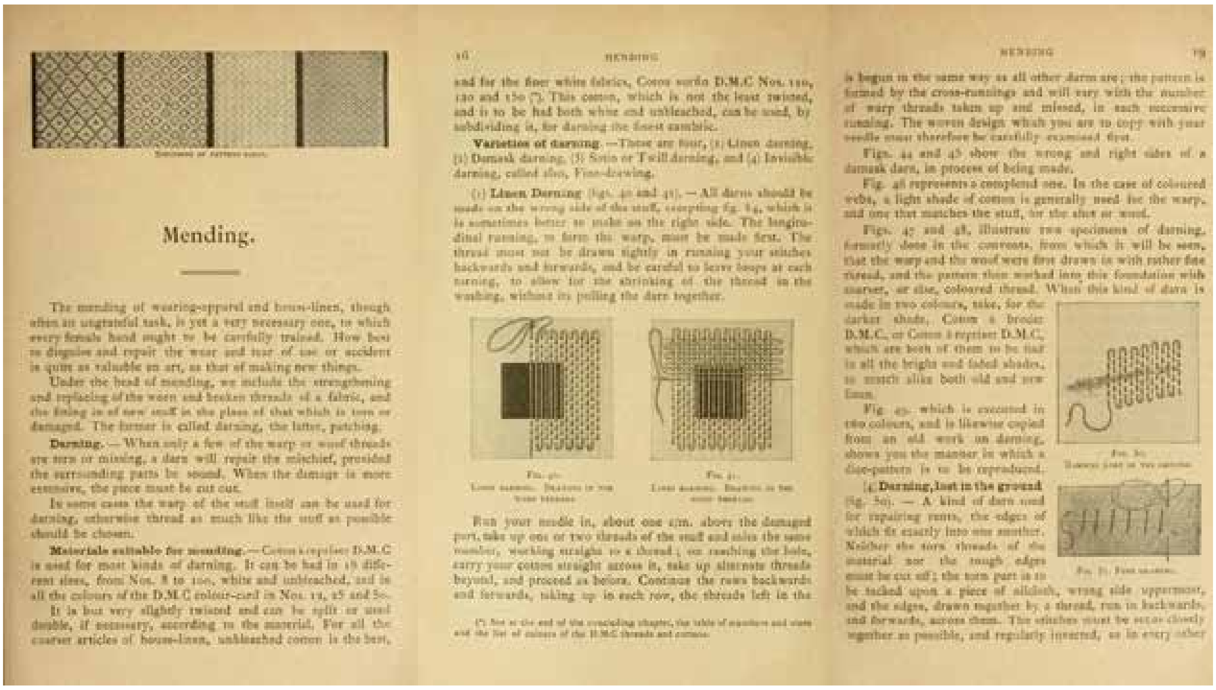
Fig. 26.3 Darning with a darning mushroom (left)(Photo: Courtesy of Fellisimo) and the statue of Elenor Rigby in Liverpool U.K. (Photo: Mie Ishii)

the profession because they enjoy needlework and are proud of their skills; thus, they may feel offended if someone criticizes their "hand" or the choice of a "stitch," hence making discussions difficult.

The development of textile conservation and its expansion

In a case study of conserving flags at the Museum of National Antiquities, the Swedish pioneer in textile conservation Agnes Geijer (1898–1989) noted the origins of the use of silk crêpeline as a material introduced in the 1920s from the archival conservation of books (Geijer 1957). She describes a method of sandwiching a silk flag with crêpeline and stitching the layers together. Hers was the first case study on the conservation of historical textiles in an international, peer-reviewed journal. Geijer held a doctorate in archaeology, specializing in textiles, and trained the first generation of European leaders in this field, including Vera Trudel (1919–1959), from Switzerland, and Sigrid Müller Christensen, a German who founded the textile workshop at the Bavarian National Museum in Munich. Dissemination of the Swedish methodology is evident in the National Museum of Denmark's Studies in Museum Technology 2: Conservation of Textiles, which includes a diagram of a couching stitch (Jacobi et al. 1978). Mechthild Flury-Lemberg, who established textile conservation at the Abegg Stiftung in Switzerland, was among the first trainees under Müller's supervision in Munich (Niekamp 2011). Flury-Lemberg's monumental publication Textile Conservation and Research also explained the couching stitch (Flury-Lemberg 1988). This Swedish line appears to be the basis of textile conservation in Europe. Danish-born Karen Finch, who trained at the Victoria and Albert Museum in London, established the Textile Conservation Centre and started the first post-graduate course, in affiliation with the Courtauld Institute of Art, in 1975. She included photographs of couching stitches in Finch and Putnam (1986). British-born Sheila Landi, who trained and taught at the Victoria and Albert Museum, explained couching as "the most important stitches in conservation," in The Textile Conservator's Manual (Landi 1992). Textile conservators in North America produced collective notes on stitching, such as the CCI Note 13/10 (CCI 1985) and the Directory of Hand Stitches Used in Textile Conservation (Grimm 1992), available online due to the efforts of members of the American Institute for Conservation's Textile Specialty Group[2]. Individual training, expert publications, and selective and collective output have thus shaped textile conservation stitching in the latter half of the 20th century.

The list of references in the Directory of Hand Stitches Used in Textile Conservation includes the Encyclopedia



Mending.

Fig. 26.4 From Dillmont (1900)

of Needlework, first published by Dillmont in 1890. This popular hand-size volume has been reprinted many times over the years and translated into 17 languages. In the chapter “Mending,” Dillmont describes this needlework as follows (Figure 3):

> The mending of wearing-apparel and house-linen, though often ungrateful work, is yet a necessity to which every female hand ought to be carefully trained. How best to disguise and repair the wear and tear of use or accident is quite as valuable an art as that of making new articles. Under the head of mending we include the strengthening and replacing of the work and broken thread of a fabric, and the fitting in of new stuff in the place of that which is torn or damaged. The former is called darning, the latter patching. (Dillmont 1990)

The textile conservation communities in Europe and the US tend to use similar methods of stitching. Nilsson (2015) surveyed the stitches used in textile conservation and reported that, among the many stitches described in the literature, in the conservation of a historical silk costume, conservators in Europe and the US tend to use only three:

- backing with laid thread and couching to secure the damage;
- overlay with running stitch to protect a damaged and frayed area; and
- backing with brick couching to secure the damage.

The reason for this, as previously explained, is the line of education and a collective system that has played an important role in the choice of stitching methods used to reinforce a historical textile.

In 1993, during my education at the Textile Conservation Centre, affiliated with the Courtauld Institute of Art, the 1st year curriculum included conservation stitching, readings on the philosophical issues in conservation, and practical case studies. Students were encouraged to think about the reasons behind the choices, as part of their career preparation. This educational approach has produced a generation of textile conservators with similar attitudes and skills, as demonstrated in the study by Nilsson.

The fact that darning was excluded from instructional texts explains why I did not learn darning during my training. Although “mending cloth” [i] is the foundation of textile conservation, this method was consciously omitted, and thus also not taught at a post-graduate course in the mid-1990s. Why was it excluded, despite being “as valuable an art as that of making new articles” (Dilmont 1990)? Why does the continuity of the daily care of cloth cease once that cloth has gained historical value?

History in heritage conservation explains an aspect

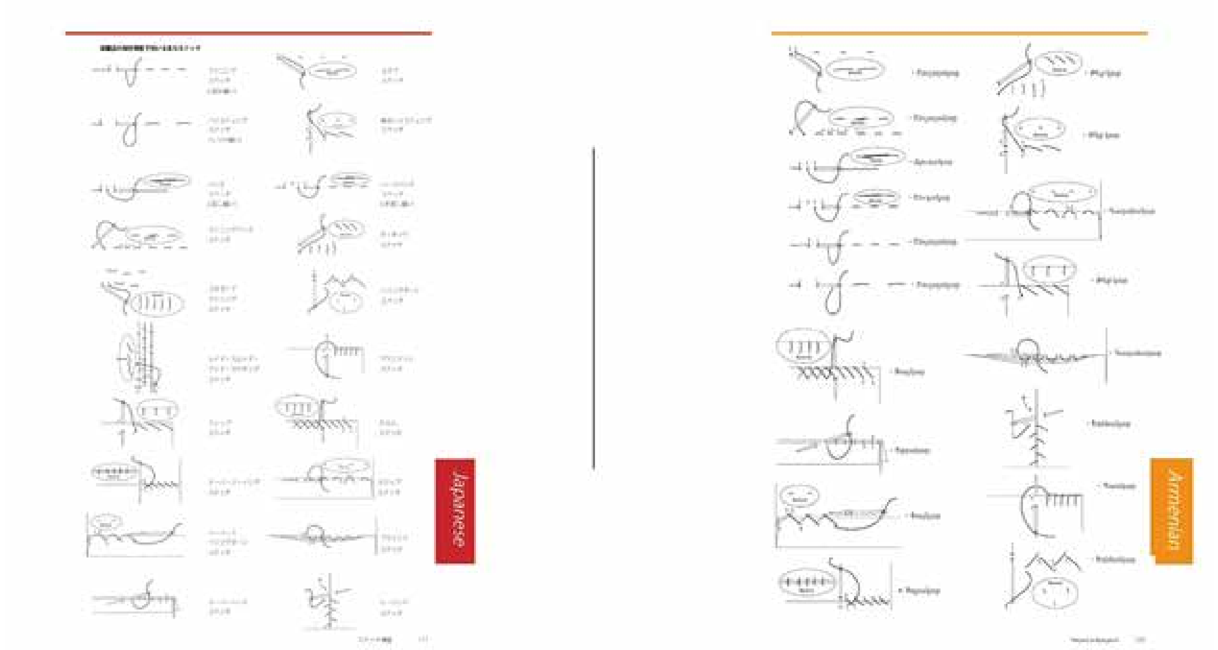


Fig. 26.5 Introducing European-North American stitches used in textile conservation in Japanese (left Ishii 2015a) and in Armenian (right)Ishii 2015b).

behind this thinking. The Austrian art historian Alois Riegl (1858–1905), who transformed the value concept of monuments of the 20th century, argued that "according to the cult of age value, what is required to keep a monument 'alive,' in use, is not necessarily concessions to either use value or its aesthetic counterpart, newness value, but rather a sacrifice of virtually everything that constitutes age value in a monument" (Riegl 1903).

An alternative art of conservation stitching

Overseas students, like myself, returning to their home countries apply the knowledge and skills gained during their training. In many cases, they are the first graduate-school-trained textile conservators in their native countries. These newly minted textile conservators have contributed to disseminating the use of selected stitches as "textile conservation stitching" (Kim 2011, Ishii 2015a, 2015b, and 2016a). Little did I think about the impact I was making when I taught textile conservation to students in Japan, Armenia, Egypt, and Taiwan, until I had the opportunity to work closely with textile conservators in Japan, most notably Yoshimi Shiroyama and Naomi Yoda, who as part of Shōkakudo Conservation Studio work on historical textiles of registered national and important treasures under the supervision of the Agency for Cultural Affairs.

In Japan, a historical kimono, whether in a museum collection or in private hands, is designated as cultural property and continues its life of being cared for in the daily manner and repaired (Koshiishi 2018). There are considerations and implementations of the methodologies of the West, but unless a kimono is seriously degraded and taken out of its cultural continuity method of care, it will be handled in the same manner as it would be if in private hands.

This unique system was introduced outside Japan through a series of workshops directed by Masato Katoh of the Tokyo National Institute of Cultural Property. A two-week program was held in Taipei, Taiwan, in cooperation with Yuan-Feng Chang at the Taiwan Normal University in 2017–2019. The aim was to provide information and encourage the understanding and care of Japanese textiles in collections outside Japan. It was also an opportunity for Japanese conservators, curators, and scientists to form a joint program on textile conservation. Oyama Yuzuruha, curator of textiles at the Tokyo National Museum, demonstrated the handling, display, and storage of kimonos in a museum. She

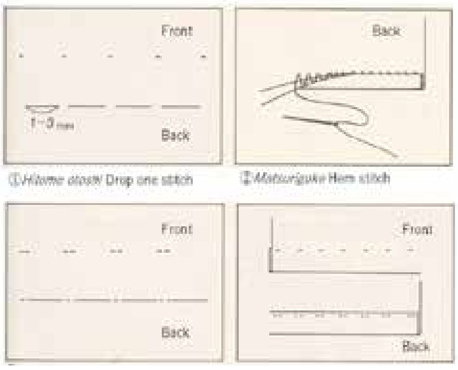


Fig. 26.6 Example of kimono sewing stitches (Murabayashi 1990)

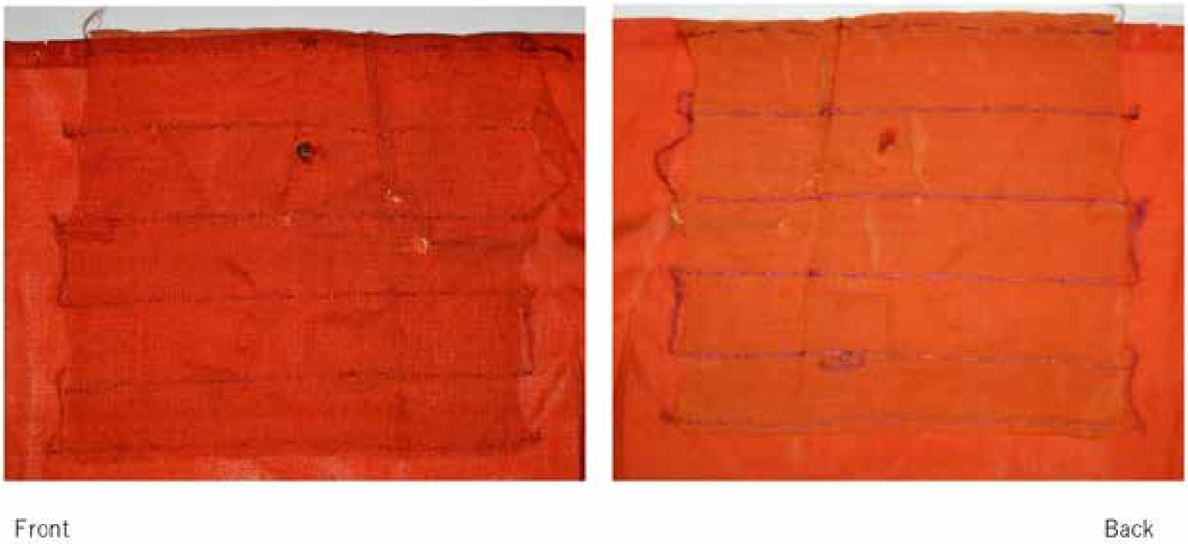


Fig. 26.7 . An example of a patch on an antique kimono (author's collection). Futatsume otoshi (drop two stitch), a stitch used for kimono sewing, is used in alternate rows to hold the patching fabric in place. In the workshop, the same stitching method was explained as being used in historical kimono repair in Japan. (Photo: Mie Ishii)

showed how a kimono is exhibited, using an eko, a clothes hanger for kimonos or a T-shaped stand that shows off the design from the back side, as a kimono is designed to be viewed from the back (Oyama 2019). She also demonstrated folding a kimono for storage and placing it into an envelope known as tatō-shi, made of mulberry paper. Her presentation included images of the museum storage of kimonos with chests made of Kiri wood (Paulownia), a traditional material used for storage boxes because of its low acid emissions and its ability to absorb humidity (Oyama 2019). Shiroyama and Yoda led stitching practice sessions on kimono repair and storage (Shiroyama and Yoda 2019a and 2019b). The session introduced specially prepared hand-reeled and hand-woven silk to reinforce a kimono fragment (Ishii and Shimura 2017). The supporting texts cannot be reproduced here, but the stitches used are common kimono sewing stitches and patching methods. Figure 4A shows examples of stitches used for kimono sewing and Figure 4B the placements of the stitch lines in the reinforcement of a historic kimono. Figure 5 provides an example of the patching of a kimono on an antique textile using a technique similar to that taught at the workshop.

Preservation of a kimono is based on a holistic approach aimed at preserving the tangible historical textile bearing in mind the intangible techniques associated with the production of the material. The methodologies applied to preserve a historical kimono are not separated from those used in its daily care, even after the textile enters a museum. Now that the Japanese have almost completely stopped wearing kimonos, curators and conservators are aware that they have an added responsibility to keep up the body of knowledge developed for their maintenance, which includes the methods for handling, making, and repair that have been handed down for generations. Hence, textile conservation of Japanese ethnic attire can be viewed as living heritage (Ishii 2016b).

In the past, cloth was regarded as a precious commodity, as it was not easily made or obtained. The act of repairing and mending cloth exemplifies what we value. In the West, mending cloth was previously a humble art equivalent to new creations. In Buddhist belief, it is an expression of virtue and the wabi-sabi view of the world is that incompleteness adds value. After a century in which ethnographic domestic mending and darning were rejected for textile conservation stitching, it is time to realize what was lost and what can be gained. There is also a need to rethink the philosophy that guides our choices as textile conservators and the methodology that underlines our decision-making and practice. Looking beyond our boundaries will provide a broader perception that will enrich the art of textile conservation.

Conclusion

Textile conservation stitching is a sensitive topic of discussion even among contemporaries in the field. The traditional Western education widespread in the profession has come to dictate what conservators think is the correct approach but this may narrow both thinking and methodologies. Using the example of conservation stitching, this paper has pointed out that, during the last century, textile conservators' selectiveness and their eagerness to develop a profession in the heritage sector resulted in a departure from domesticity and a restriction of our choices and decision-making options, issues that are also reflected in other areas of conservation conduct. The arguments presented herein are not intended to provide a direction for the future or to insist that textile conservation include living heritage. The Japanese system is legally binding and also has issues that limit its perspective. The concept of diversity in conservation approaches will not be integrated if a culture is viewed as absolute. A spirit of tolerance and a sense of historical consciousness are necessary to acknowledge differences as an independent culture. Openness and dialogue are encouraged and are the keys to overcoming the challenges inherent in textile conservation, by rethinking our practices and recognizing new opportunities beyond our perspectives. The author hopes that this paper will stir an open debate about how we preserve our textiles. The wabi-sabi philosophy may lead us to an appreciation that "nothing lasts, nothing is finished, and nothing is perfect."

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Notes

1. The author has not seen the exhibition but was able to hear Kate Irvin's presentation—"The creative destruction of brokenness: Japanese boro, repair and fashion futures"—at the ICOM Costume Committee Program, ICOM Kyoto 2019 General Conference, 3 September 2019, Museum of Modern Art, Kyoto. The exhibition's website can be found at https:// risdmuseum.org/exhibitions-events/exhibitions/repair-and-design-futures (accessed 15 November 2019).

2. https://www.conservation-wiki. com/wiki/Directory_of_Hand_Stitches

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